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Measurement of the Magnetic Moment of the Omega Minus Hyperon

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Abstract

An experiment for determining the magnetic moment of the Ω^- hyperon is proposed. A polarized Ω^- sample is produced by 800 GeV protons or negatively charged strange baryons. The polarization vector is precessed in a magnetic field and the decay products of the $\Omega^- \to \Lambda K^-$ are detected with a conventional magnetic spectrometer. A precision of $\delta\mu_\Omega \leq 0.1$ nuclear magneton can be achieved in 1000 hours of running in Proton Center.

Introduction

One of the important static properties of an elementary particle is its magnetic moment. The excellent agreement of the QED calculation and the experimental values of the electron and muon magnetic moments has long been considered one of the great successes in physics. The situation is not as clear in the hadron sector. Hadrons are composite objects which are made up of quarks and the dynamics of quarks inside hadrons are not well understood. The recent discovery that hyperons produced by protons in inclusive interactions are polarized[1] makes it possible to determine the hyperon magnetic moments with high precision.[2] Using the experimental values of the proton, neutron and lambda magnetic moments, the other hyperon moments can be, in principle, predicted to 1 % accuracy. The measured values and the predictions of the baryon magnetic moments are shown in Table 1. The discrepancies are statistically significant. Various effects that may improve the predictions, such as configuration mixing, anomalous quark moments, pion cloud contributions and relativistic corrections, have been proposed.[3] Nevertheless, as can be seen in Table 1, the global improvement is small. For the Ξ^-, in the worst case, the difference can still be of the order of 30 %. It has been speculated that the mismatch of the calculations and the measurements is because the strange quark behaves differently in different environments.

When the environmental dependence, the quark moments and some of the mentioned corrections are parametrized in terms of the seven measured baryon magnetic moments, one can then predict the magnetic moment of the Ω^-. Using the non-relativistic quark model, Georgi and Manohar predicted $\mu(\Omega^-) = 3\mu(s)$ to be -2.25 +/- 0.09 n.m..[4] This is different from the SU(6) calculation which gives $\mu(\Omega^-) = 3\mu(s) = 3\mu(\Lambda) = -1.84$ n.m.. Lipkin recently proposed a "two-component model"[5] in which one component is the additive SU(3) quark model with all quarks behaving like strange quarks, and the second component is a non-additive mechanism which affects only non-strange quark contributions, thus breaking the SU(3) symmetry. He concluded that $\mu(\Omega^-) = 3\mu(s) < 3\mu(\Xi^-) < -2.2$ n.m..

Alternatively, one can work out the baryon magnetic moments from QCD using the QCD sum rule or lattice calculations. In principle, these QCD calculations should have the same predictive power as those of QED. Based on a lattice calculation without considering the effects of the virtual quark pairs, Bernard et al. found that $\mu(\Omega^-) =$ -1.7 +/- 0.6 n.m..[6] It is important to point out that both Georgi et. al. and Lipkin concluded configuration mixing in

Ω^- is zero. This implies that Ω^- is the simplest system in which to understand the behaviour of the strange quark. Therefore, a precise measurement of $\mu(\Omega^-)$ is very interesting.

Experimentally, there has been only one attempt to determine $\mu(\Omega^-)$.[7] In E620, Ω^-'s were produced by 400 GeV protons incident on a solid beryllium target, with average x of 0.5 and p_t of 1 GeV. After passing through a magnetic channel, the charged particles of the $\Omega^- \to \Lambda\ K^-$ decay were detected with the Neutral Hyperon Spectrometer. In all, 1,743 reconstructed $\Omega^- \to \Lambda\ K^-$ decays were collected and an average polarization of the Λ from the Ω^- decay of 0.12 +/- 0.08 was measured. Using this polarization signal, $\mu(\Omega^-)$ was determined to be -2.1 +/- 1.0 n.m.. If the E620 Ω^- polarization signal is considered statistically significant it implies that the magnitude of the vector polarization of the Ω^- is between 10 and 20 %. This should be compared with that of the other hyperons <u>produced by protons</u> in inclusive reactions. In the case of the Λ, Ξ^0 and Ξ^-, the magnitude of the polarization is of the order of 15 % in the same kinematic region. The polarization increases as a function of x and p_t, up to p_t of 1 GeV. For p_t > 1 GeV, the Λ polarization is found to be proportional to x only.[1] In contrast to Λ's and Ξ's, $\bar{\Lambda}$'s produced by protons in the same kinematic region are not polarized at all. It appears that the strange quark is either produced polarized by some unknown mechanism or is polarized as it combines with the leading spectator quark or diquark to form the hyperon. On the other hand, even though the $\bar{\Lambda}$ and the Ω^- do not contain any quark common to the proton, the production cross sections of the $\bar{\Lambda}$ and the Ω^- by protons in the same kinematic region are quite different. The invariant production cross section of the Ω^- behaves like $(1-x)^5$, in contrast to that of the $\bar{\Lambda}$ which is $(1-x)^{7.5}$. Thus, it is difficult to conclude whether or not the Ω^-'s <u>produced</u> <u>by</u> <u>protons</u> should be polarized.

Therefore we propose two parts for this experiment. In the first part, the primary proton beam in Proton Center will be used to produce Ω^-'s which then pass through a momentum selecting channel embedded in the Proton Center hyperon magnet. If the Ω^-'s are polarized this same magnet will serve to precess the polarization vector. With about 100 hours of running, the polarization of the Ω^- can be measured to a precision of 2 %, or better. We have to emphasize that a null polarization of this part is very interesting in itself as it provides further information about the inclusive hyperon polarization mechanism. In particular, it would indicate that the strange quark is not produced polarized.

In the second part of the experiment, we shall make use of the leading particle mechanism to create the Ω^-. Only the equipment upstream of the Proton Center hyperon magnet is modified. The Ω^-'s are produced by a negatively charged strange beam created from the primary proton beam incident on a target upstream of the Ω^- production target. A magnet positioned between the targets is used to select the momentum of the negatively charged beam and to sweep away the primary proton beam.

Experiment

Charged Hyperon Production by Protons

Figures 1a and 1b show an elevation view and a plan view of the set-up which is upstream of the spectrometer. The proton beam is deflected in the vertical plane by an upstream vernier magnet and is restored to the hyperon target T2 by a set of dipoles M1. This bend string is the same as the one requested in P732. M2 is a 5 m long magnet which is not turned on in the first part of the experiment. The proton beam will pass through the aperture of M2. A 1 mm. square half interaction length beryllium target is used to produce the charged hyperon beam. The production angle will be +/- 2.5 mrad for an 800 GeV proton beam. The hyperon polarization is produced in the horizontal plane and is precessed by the vertical field of the 7 m long magnet M3. The curved channel inserted in the hyperon magnet is shown in Fig.2. It is made up of brass blocks, each with a straight cylindrical hole approximately centered on the circular arc of the central orbit. The middle block and the last block at the downstream end are reinforced by circular tungsten inserts. A 17.5 mrad bend is defined by the centers of the beryllium target, the central 5 mm diameter tungsten collimator, and the 12 mm diameter output collimator. Displacement of the central orbit from the infinite momentum orbit at the exit of the channel is 63 mm.

The inclusive production cross sections of hyperons by protons at 2.5 mrad and 800 GeV have not been measured. However, these were determined at 5 mrad with 400 GeV protons on a beryllium target in E620.[7,8] In order to estimate the negative particle fluxes in this proposal, the invariant inclusive cross section $E\frac{\delta^3\sigma}{\delta p^3}(p + Be \rightarrow Y + X)$, where $Y = \pi^-, \Sigma^-, \Xi^-$ or Ω^-, was assumed to scale in the variables x and p_t between 400 GeV and 800 GeV. The calculated particle ratios at the target are consistent with the CERN charged hyperon measurements[9] and the E497 results.[10] Integrated fluxes at 8 m away from the target per 10^{10} incident protons are provided in Table 2. With a field integral of 23.44 T-m (17.58 T-m), close to the maximum of 24.00 T-m, the Ω^- momentum spectrum after transmission through the 7 m long magnetic channel is shown in Fig.3a (Fig.3b). The spectra of the other particles are similar.

<u>Charged Hyperon Production by Negatively Charged Strange Beam</u>

Fig.4a and Fig.4b show the elevation and plan views of the apparatus upstream of the spectrometer. In this part of the experiment, the primary proton beam will hit one of the two 1 mm square half interaction length tungsten targets, T1. The incident angle of the proton beam is 0 mrad. The tungsten targets are placed in front of the entrances of two magnetic channels which lie in a vertical plane and curve toward each other. These channels are made up of brass blocks, each with two straight cylindrical tubes laid out in the same manner as described before. Since the radius of the channel in the 1 m long middle block is 2 mm and 3 mm in the last block, the beam divergence in the transverse direction is small. The separation of the centers of the central orbits is 4 cm at the upstream end of M2, 3.5 cm at a distance of 3 m away from the tungsten targets and 1 cm at the downstream face of M2. A 1 cm square, one interaction length long copper target T2 is positioned 1 m downstream from the exits of the channels in M2. The central rays which emerge from the collimator will hit T2 at +/- 5 mrad, corresponding to the primary proton beam striking the bottom or top T1 target respectively.

The flux and composition of the negative beam produced by protons at 0 mrad is calculated using the invariant cross sections $E\frac{\delta^3\sigma}{\delta p^3}(p+Be \rightarrow Y+X)$, where $Y = \pi^-, \Sigma^-, \Xi^-$ or Ω^-, measured at 2 mrad by the CERN hyperon group,[9] assuming scaling in x and p_t is valid between 200 GeV and 800 Gev, and the atomic number dependence is $A^{2/3}$. The yield is given in Table 3. The momentum spectrum of the Σ^- at 6 m away from the tungsten target is shown in Fig.5.

In order to estimate the hyperon yields with the negative beam hitting the copper target, the following argument is employed. The production of a Ξ^-(dss) from a proton(uud) and an Ω^-(sss) from a Σ^-(dds) is similar in the sense that two new quarks are created. Thus the production cross section of the former process at 5 mrad and 400 GeV is used to calculate the yield of the Ω^- from Σ^-'s. The other interactions are worked out in a similar fashion by relating one to the others that have been determined. Table 4 shows the yields of the negatively charged hyperons at 8 m downstream from the copper target with a 5 mrad negative beam intensity of 10^8. With a field integral of 17.58 T-m, the momentum spectrum of the Ω^- downstream of the collimator in M3 is shown in Fig.3b.

Charged Hyperon Detection

The layout of the spectrometer in plan and elevation view are shown in Fig.6. It is similar to the set-up used in E620 for detecting the decays $\Xi^- \rightarrow \Lambda \pi^-$ and $\Omega^- \rightarrow \Lambda K^-$. The length of the detector is about 50 m. The apparatus is lined up with respect to the axis which is tangent to the central orbit at the exit of the channel in M3. The momentum analyzing magnets, M4 and M5, are BM109 magnets which have been used in previous experiments done in Proton Center. These magnets will be operated to provide a momemtum kick of 1.4 GeV which is sufficient to bend the negative and positive particles from a $\Xi^- \rightarrow \Lambda\pi^-$ or an $\Omega^- \rightarrow \Lambda K^-$ decay to opposite sides of the last wire chamber. The trigger will require a charged track upstream of M4 and at least one negative track as well as a positive track downstream of M5. That is, there must be a $\Lambda \rightarrow p\pi^-$ in the decay and this will eliminate the directly produced π^-'s, K^-'s and Σ^-'s. In logic symbols, the trigger is S1.$\overline{\text{S2}}$.S3.S4.S6. A similiar trigger, S1.$\overline{\text{S2}}$.C4.C7L.C8R.S6, was employed in E620 and the trigger rate was about 200 Hz with a 15 sec machine cycle. The yield of this trigger was of the order of 6 % and provided a good $\Xi^- \rightarrow \Lambda\pi^-$ sample that was free of backgrounds.[11] The trigger in this experiment is tighter and should provide a higher yield of three track events. The Ξ^- sample will also be analysed because it serves as another means to study systematic problems, if any. This is important for polarization measurements. Table 2 shows the detection efficiencies of $\Xi^- \rightarrow \Lambda\pi^-$ and $\Omega^- \rightarrow \Lambda K^-$. The efficiencies are about 25 % higher when the momentum of the Ξ^- and the Ω^- is 280 GeV. Since the decay topology of $\Xi^- \rightarrow \Lambda\pi^-$ and $\Omega^- \rightarrow \Lambda K^-$ is the same, it is necessary to identify the negative tracks or apply software cuts in order to extract a clean sample of Ω^-'s. The latter method was used in E620. The cuts removed about 45 % of the genuine Ω^-'s, but background under the mass peak in the final sample was reduced to about 3 %. The Λ-K^- invarant mass distributions, before and after cuts, are shown in Fig.7a and Fig.7b respectively. Note that the vertical scale of Fig. 7b is logarithmic. The possibility of using a Cherenkov counter to identify the negative tracks (K^- vs π^-) is under investigation.

Magnetic Moment Measurement

The magnetic moment of the Ω^- (or Ξ^-) is defined as

$$\mu = \frac{g}{2}\,\frac{q}{m}\,s \qquad (1)$$

where q, m and s are the charge, the mass and the spin of the Ω^- respectively, and the (g/2) factor will be determined by the experiment. Because of the geometry of the apparatus, the spin and the momentum are normal to the magnetic field in the channel. These two vectors precess in the horizontal plane. The precession angle of the spin with respect to the momentum direction is given by

$$\theta = \frac{q}{m\beta}\left(\frac{g}{2}-1\right)\int B\,dl \qquad (2)$$

where β = v/c $\cong$ 1 in this proposed experiment.[12] It is interesting to note that this expression is valid for Ω^- even though its spin is 3/2.

After reconstruction of an event $\Omega^- \to \Lambda K^-$, $\Lambda \to \pi^- p$, the direction cosines ($\cos\theta_x$, $\cos\theta_y$, $\cos\theta_z$) of the proton in the Λ rest frame can be calculated. Here the coordinate axes are such that z is along the beam axis, x is horizontal, and y is vertical. The components P_x, P_y, P_z of the Λ polarization can be calculated for a reconstructed sample by determining the asymmetries of the form

$$\frac{\delta N}{\delta \cos\theta_i} = (1/2)(1 + \alpha_\Lambda P_\Lambda \cos\theta_i) \qquad i = X,\ Y,\ Z \qquad (3)$$

Geometrical biases in the apparatus which distort the distributions can be calculated with Monte Carlo techniques. Parity conservation requires $P_y = 0$. If the sign of the proton production angle is changed, P_x, P_z and the sense of the spin rotation are reversed, but not the biases. Thus, taking equal amounts of data with opposite production angles is vital to the elimination of apparatus biases.

The polarization vector of the Ω^- is related to the polarization of the Λ by the expression

$$\vec{P}_\Lambda = \frac{1}{2(s+1)}\left[1 + (2s+1)\gamma_\Omega\right]\vec{P}_\Omega \qquad (4)$$

where s=3/2 is the spin of the Ω^- and γ_Ω is the decay parameter of the $\Omega^- \to \Lambda K^-$ decay. Since α_Ω is -0.026 +/- 0.026,[7,13] γ_Ω is either +1 or -1 (in the case of the Ξ^-, s = 1/2 and γ_{Ξ^-} = -0.9).[11,14] This implies that polarization of the Ω^- is

$$\vec{P}_\Lambda = \vec{P}_\Omega \qquad \text{or} \qquad \vec{P}_\Lambda = -.6\,\vec{P}_\Omega \quad .$$

The precession angle θ of Equation (2) is give by $m\pi$ + arctan(P_x/P_z), where m is an integer. The value of m is determined by taking data at several values of the precession field. For N events, the error in the measurement of a single component of the Λ polarization is

$$\delta P_\Lambda = \frac{1}{\alpha_\Lambda}\sqrt{\frac{3}{N}} \quad .$$

The error in the precession angle is $\delta\theta = \delta P_\Lambda / P_\Lambda$. Therefore, in terms of nuclear magnetons, the error in the Ω^- magnetic moment is $\delta\mu_\Omega = 1.68\,\delta(g/2)$, where, from Equation (2), $\delta(g/2) = 15/(kP_\Lambda \int Bdl \sqrt{N})$. Taking $\int Bdl$ = 23.44 T-m and an average P_Λ = 0.08 gives the formula $\delta\mu_\Omega = 13.4/(k\sqrt{N})$.

Request for Laboratory Facilities

Three 3 m dipoles are needed just upstream of the 7 m long hyperon magnet to give the maximum production angle of +/- 5 mrad. A 5 m long dipole magnet is also needed to form the negatively charged strange beam and to sweep away the primary proton beam in the second part of the experiment. A proton energy of 800 GeV to 1 TeV and an intensity greater than 10^{10} per 20 sec long spill is requested. About 250 hours of data at each polarity will be required to achieve the error $\delta\mu_{\Omega} \leq 0.10$ in the worst case k = 0.6. A total of 1000 hours in the Proton Center is requested, including tuning.

The group will supply the curved channel hardware, the MWPC's and their read-out electronics. Other electronics, CAMAC modules and on-line computer are requested.

The total number of triggers is of the order of 10^{8}. In E555, about 275,000 triggers could be logged on a tape and each tape took about 4,000 sec to process. In this experiment, the number triggers per tape will be comparable. The CPU time to analyze one tape is also about the same as E555. Therefore, 500 hours of computer time is needed.

References

1. For a review of hyperon polarization results, see B.Lundberg, Proc. High Energy Spin Physics-1982, Ed. G.Bunce (1983).

2. For a review of magnetic moment results, see L.Pondrom, Proc. High Energy Spin Physics-1982, Ed. G.Bunce (1983).

3. For a review of magnetic moment calculations, see J.L.Rosner, Proc. 20th Int.Conf. on High Energy Physics, Ed. L.Durand and L.Pondrom (1981).

4. H.Georgi and A.Manohar, Phys.Lett. 132B , 183(1983).

5. H.Lipkin, Nucl.Phys. B214 , 136(1983).

6. C.Bernard et al., Phys.Rev.Lett. 49 , 1076(1982).

7. K.B.Luk, Ph.D. thesis, Rutgers University, 1983(unpublished).

8. A.Beretvas, private communication.

9. M.Bourquin et al., Nucl.Phys. B153 , 13(1979); M.Bourquin et al., Z.Phys. C 5 , 275(1980).

10. T.Cardello, Ph.D. thesis, Yale University, 1983(unpublished).

11. R.Rameika, Ph.D. thesis, Rutgers University, 1981(unpulished).

12. V.Bargmann et al., Phys.Rev.Lett. 2 , 433(1959).

13. M.Bourquin et al., Nucl.Phys. B241 , 1(1984).

14. S.F.Biagi et al., Phys.Lett. 112B , 277(1982).

Particle	Experiment	Exact SU(6)	Broken SU(6)	Config. mixing	Pion cloud
p	2.794	input	input	2.85	2.60
n	-1.913	-1.86	input	-1.85	-2.01
Λ	-0.613±0.005	-0.93	input	input	-0.58
Σ^+	2.379±0.020	2.79	2.673	2.54	2.34
Σ^-	-1.104±0.049	-0.93	-1.091	-1.00	-1.08
Ξ^0	-1.250±0.014	-1.86	-1.435	-1.20	-1.27
Ξ^-	-0.69±0.04	-0.93	-0.494	-0.43	-0.51
Ω^-	-2.1±1.0	-2.79	-1.840	----	----

Table 1 Baryon Magnetic Moments in Nuclear Magnetons

Particle	Yield per 10^{10} p	Average momentum (GeV)	Decay mode	Detection efficiency
π^-	1.7×10^5	350	---	---
Σ^-	2.3×10^4	400	$n\pi^-$	---
Ξ^-	2300	395	$\Lambda\pi^-$	0.16
Ω^-	16	395	ΛK^-	0.22

Table 2 Negatively Charged Hyperon Yields at 8 m away from a 15 cm long beryllium target. Production angle is 2.5 mrad with 800 GeV protons.

Particle	Yield per 10^{11} p	Average momentum (GeV)
π^-	5.6×10^7	420
Σ^-	8.8×10^6	500
Ξ^-	2.3×10^5	480
Ω^-	4.2×10^3	460

Table 3 Yields of Negatively Charged Hyperons at 6 m away from a 5 cm long tungsten target with 800 GeV protons at 0.5 mrad.

Beam Particle	Yield π^-	Σ^-	Ξ^-	Ω^-
$5.6 \times 10^7 \pi^-$	1.0×10^3	9.5×10^0	8.9×10^{-1}	1.4×10^{-3}
$8.8 \times 10^6 \Sigma^-$	2.8×10^2	5.9×10^2	7.3×10^1	1.8×10^{-1}
$2.3 \times 10^5 \Xi^-$	7.4×10^0	4.5×10^0	1.6×10^1	3.9×10^{-1}
$4.2 \times 10^3 \Omega^-$	-----	-----	-----	6.4×10^{-1}

Table 4 Negatively Charged Hyperon Yields with the number of beam particle indicated in column 1 incident on a 15 cm copper target at 5 mrad. Decay loss over 8 m has been included in the yield calculations.

Particle	Yield per 10^{11} p	Average momentum (GeV)
γ	4.0×10^{9}	350
n	2.6×10^{9}	530
Λ	1.8×10^{8}	450
Ξ^{0}	2.0×10^{7}	400
K_S^{0}	2.0×10^{7}	350

Table 5 Yields of Neutral Hyperons at 6 m away from a 5 cm long tungsten target with 800 GeV protons at 0.5 mrad.

Beam Particle	Yield π^-	Σ^-	Ξ^-	Ω^-
2.6×10^{9} n	2.1×10^{5}	1.9×10^{5}	9.0×10^{2}	3.8×10^{0}
1.8×10^{8} Λ	1.5×10^{3}	1.3×10^{4}	5.5×10^{3}	1.4×10^{1}
2.0×10^{7} Ξ^{0}	4.5×10^{2}	6.0×10^{1}	5.5×10^{2}	1.0×10^{2}
2.0×10^{7} K_S^{0}	6.5×10^{0}	3.6×10^{1}	6.5×10^{0}	2.9×10^{-2}

Table 6 Negatively Charged Hyperon Yields with the number of beam particle indicated in column 1 incident on a 15 cm copper target at 5 mrad. Decay loss over 8 m has been included in the yield calculations.

LIST OF FIGURES

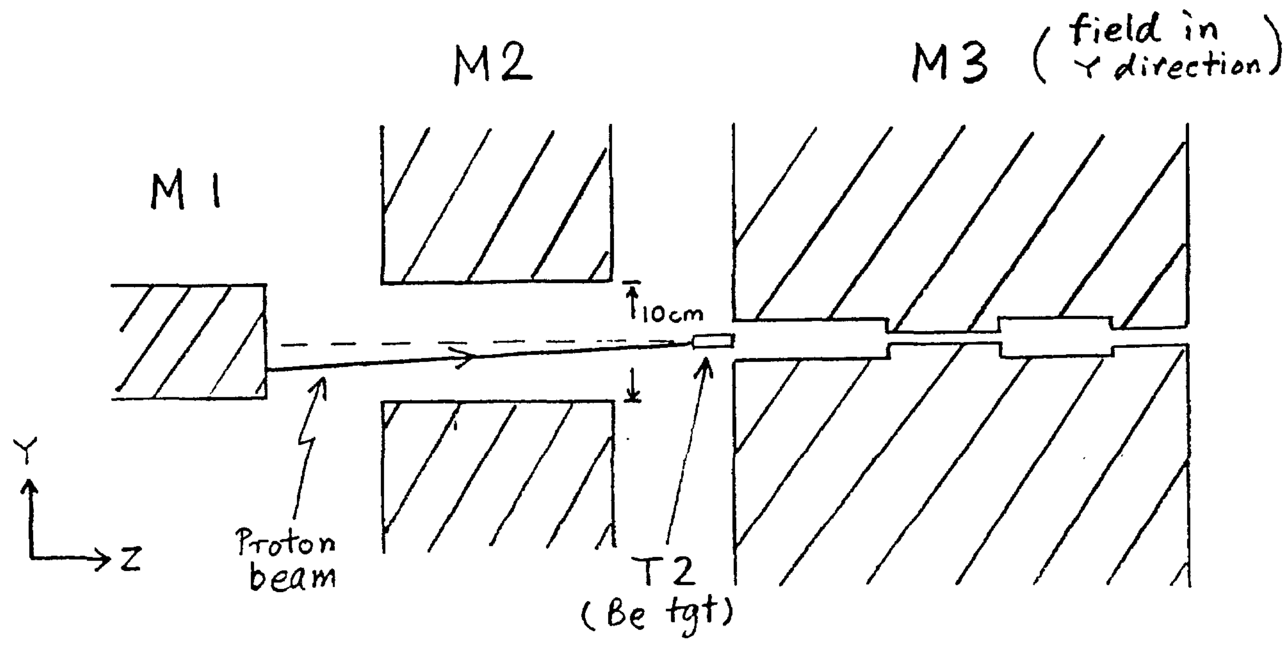


FIGURE 1a

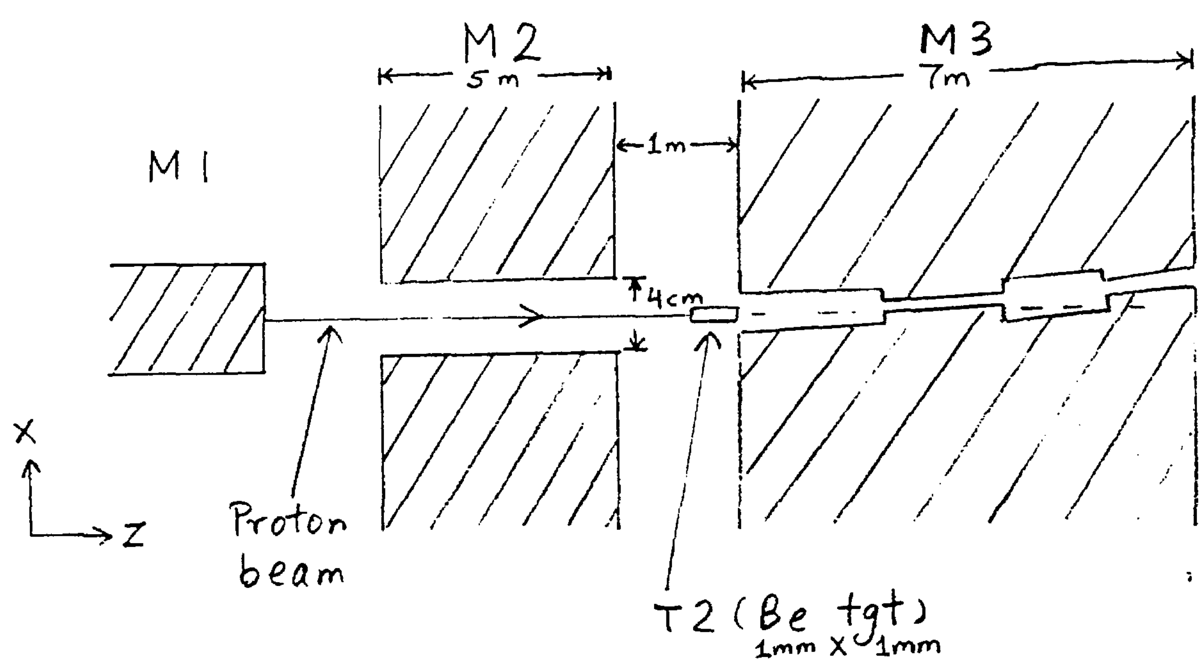


FIGURE 1b

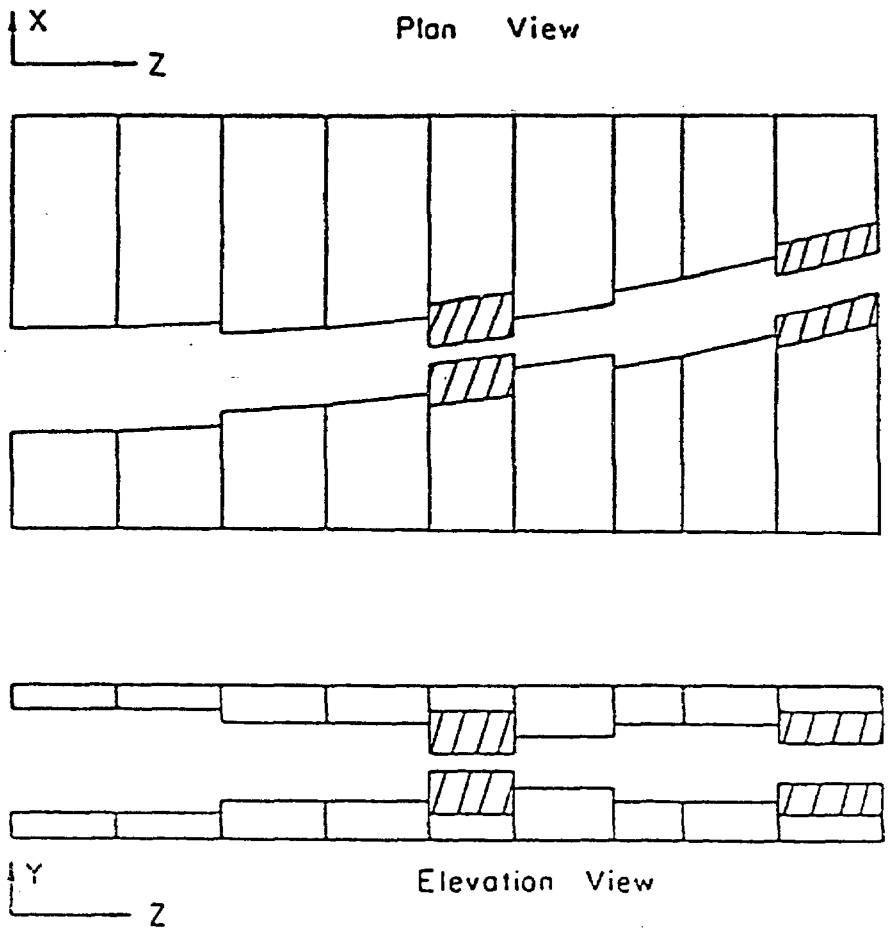


Figure 2 Plan and elevation views of the charged hyperon collimator. The cross-hatched regions represent tungsten inserts.

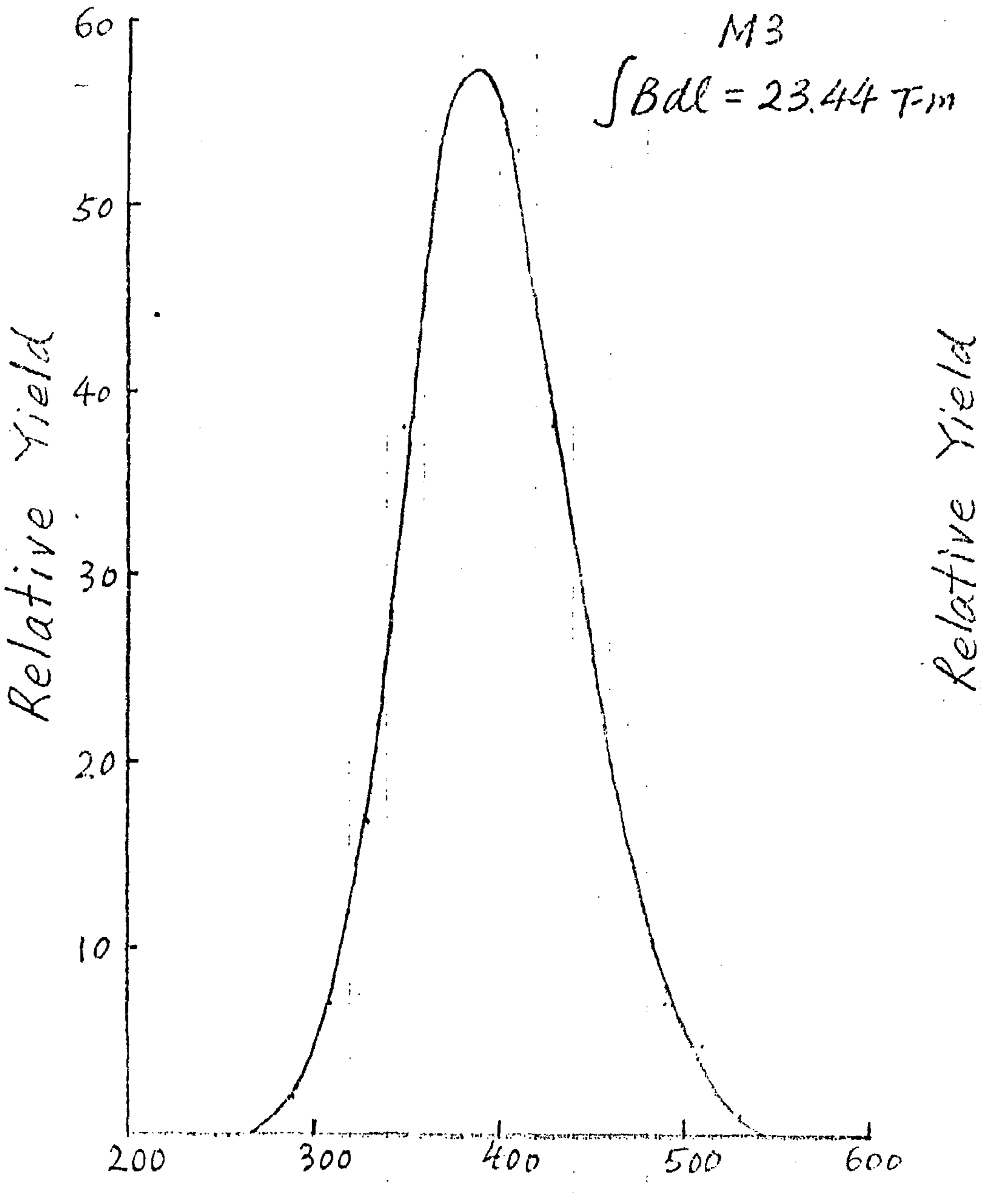


FIGURE 3a

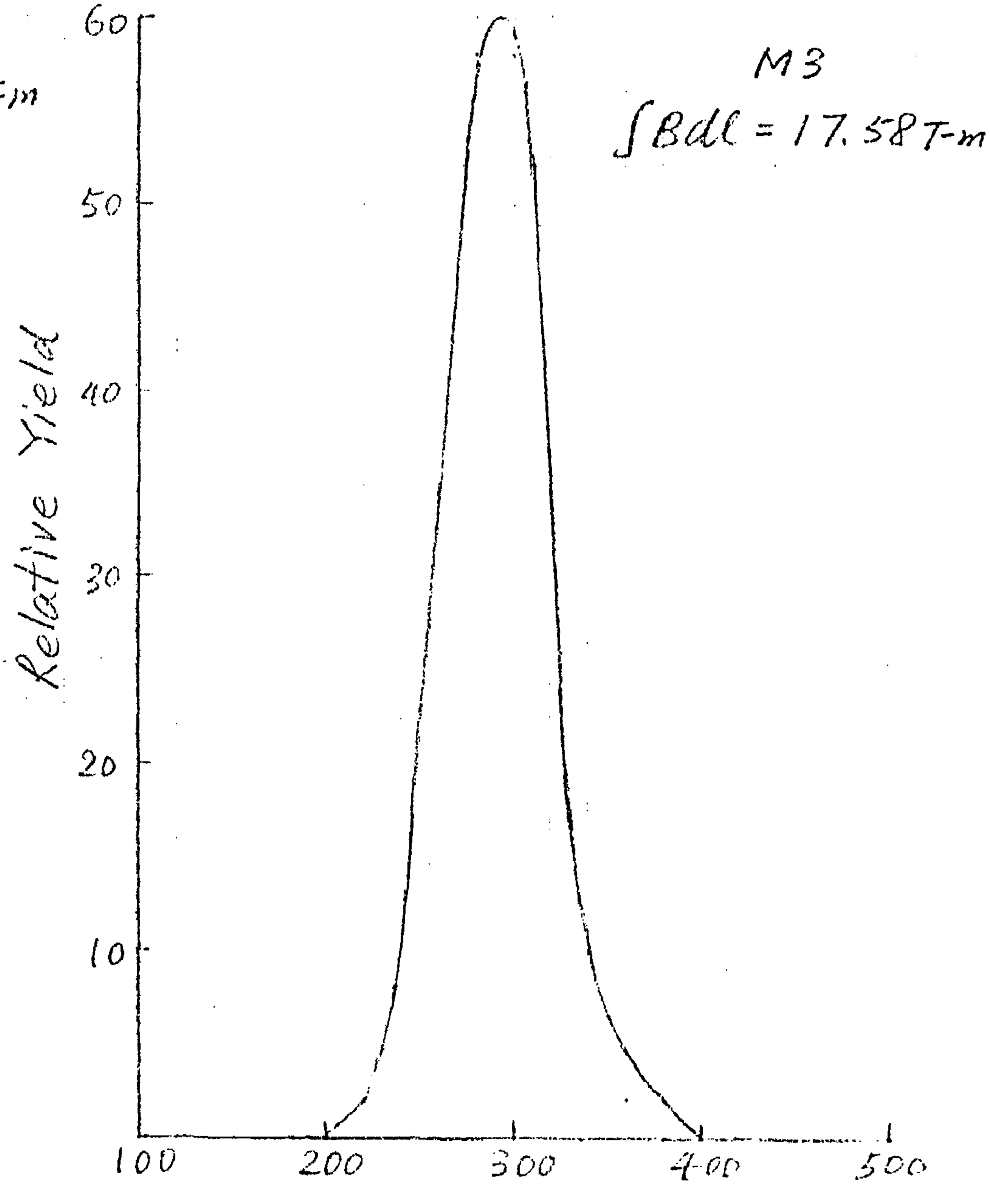


FIGURE 3b

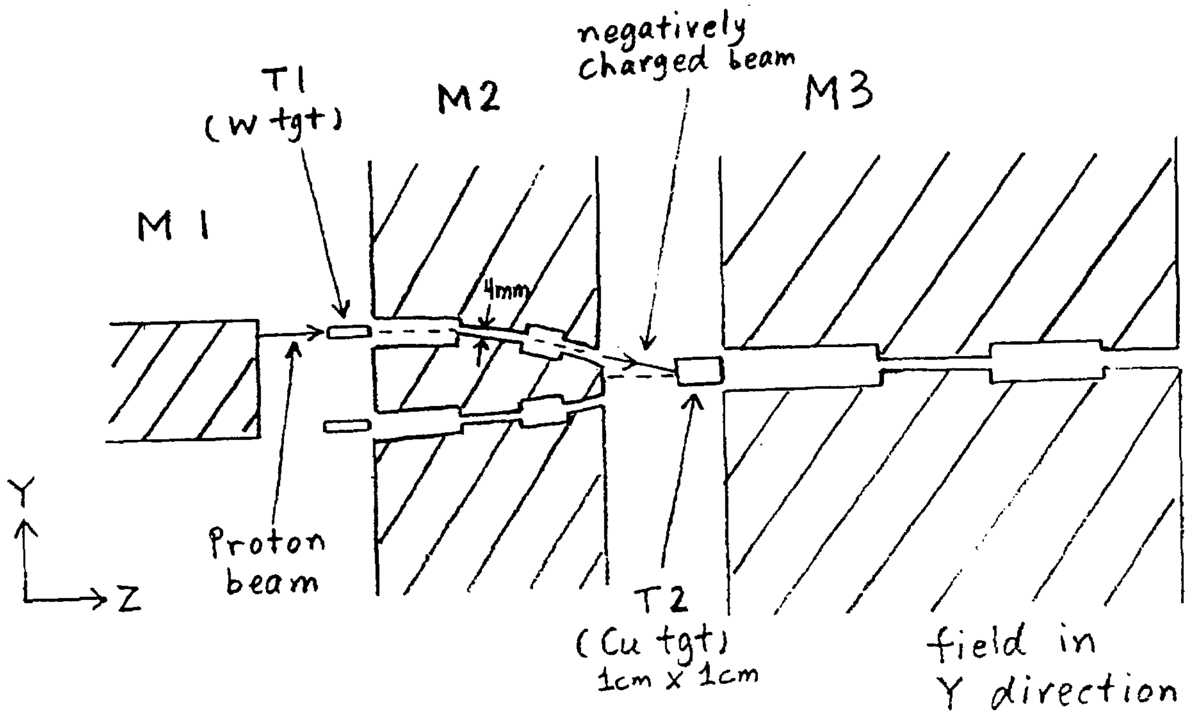


FIGURE 4a

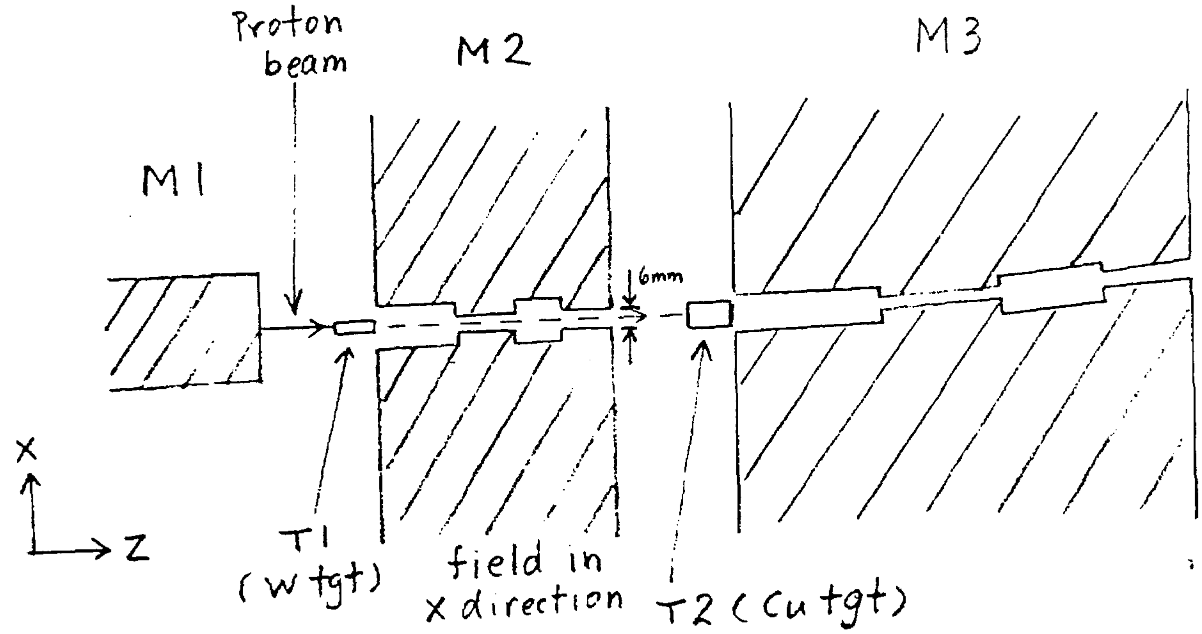
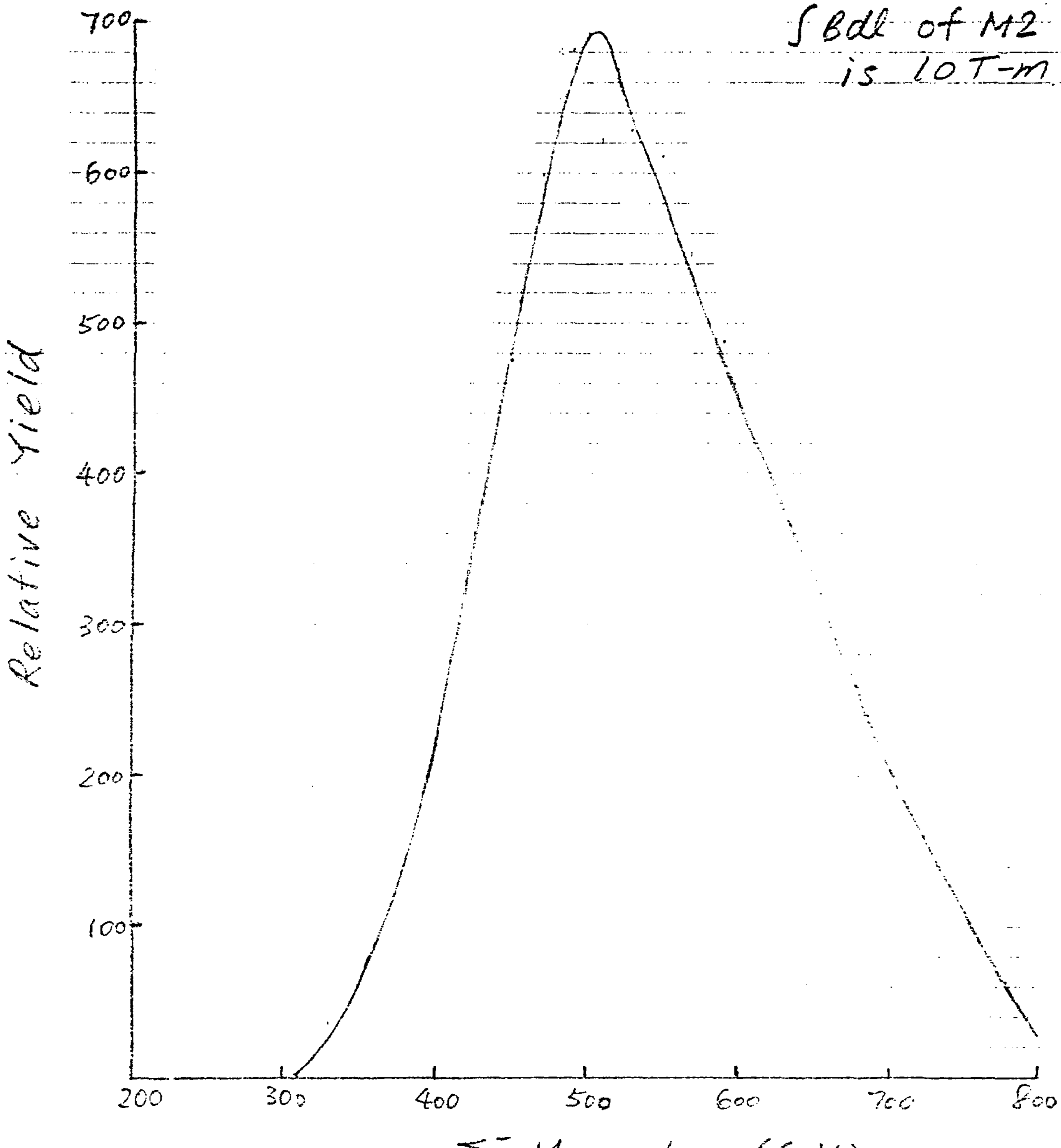


FIGURE 4b



∫Bdl of M2 is 10T-m
Relative Yield
700
600
500
400
300
200
100
200
300
400
500
600
700
800
Σ⁻ Momentum (GeV)

FIGURE 5

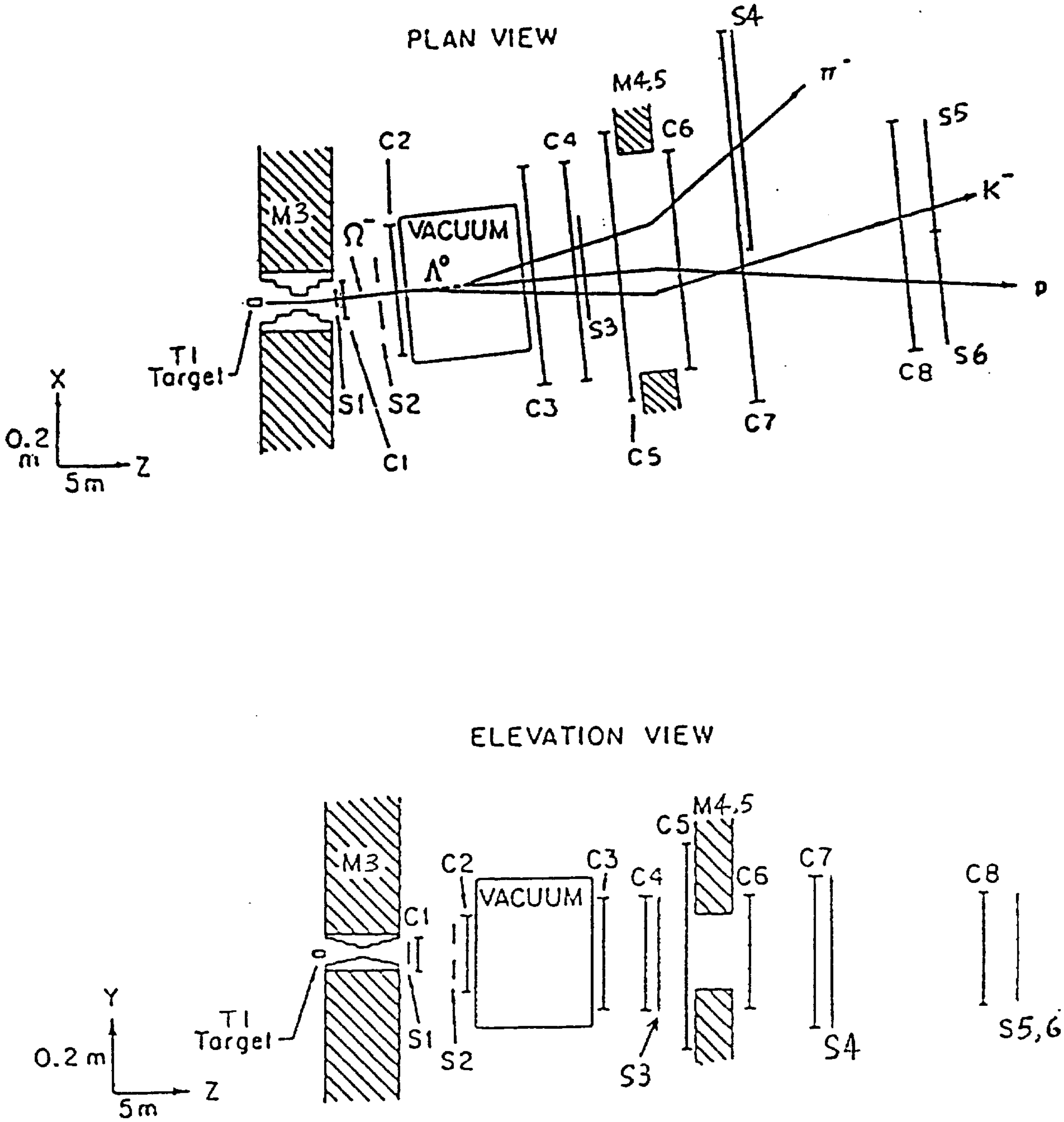


Figure 6 Plan and elevation views of the spectrometer with a typical event topology of the decay sequence $\Omega^- \rightarrow \Lambda K^-$, $\Lambda \rightarrow p\pi^-$ shown. M2-M5 are magnets, S1-S6 are scintillators and C1-C8 are multiwire proportional chambers.

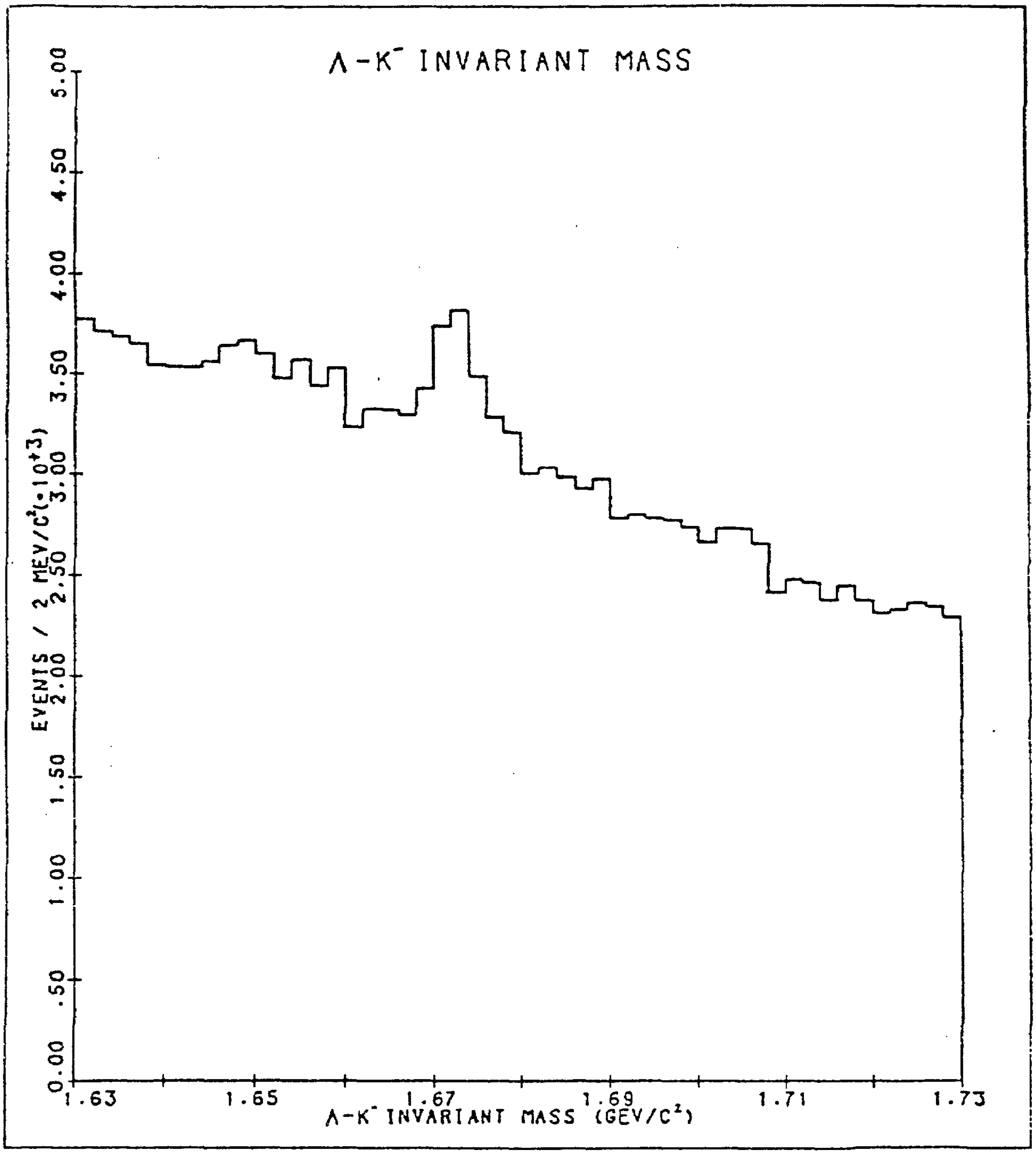


Figure 7a Λ-K^- invariant mass distribution for events with geometric χ^2 less than 100 and p-π^- invariant mass cut. The number of background events under the Ω^- peak is estimated to be about 3,200 per channel.

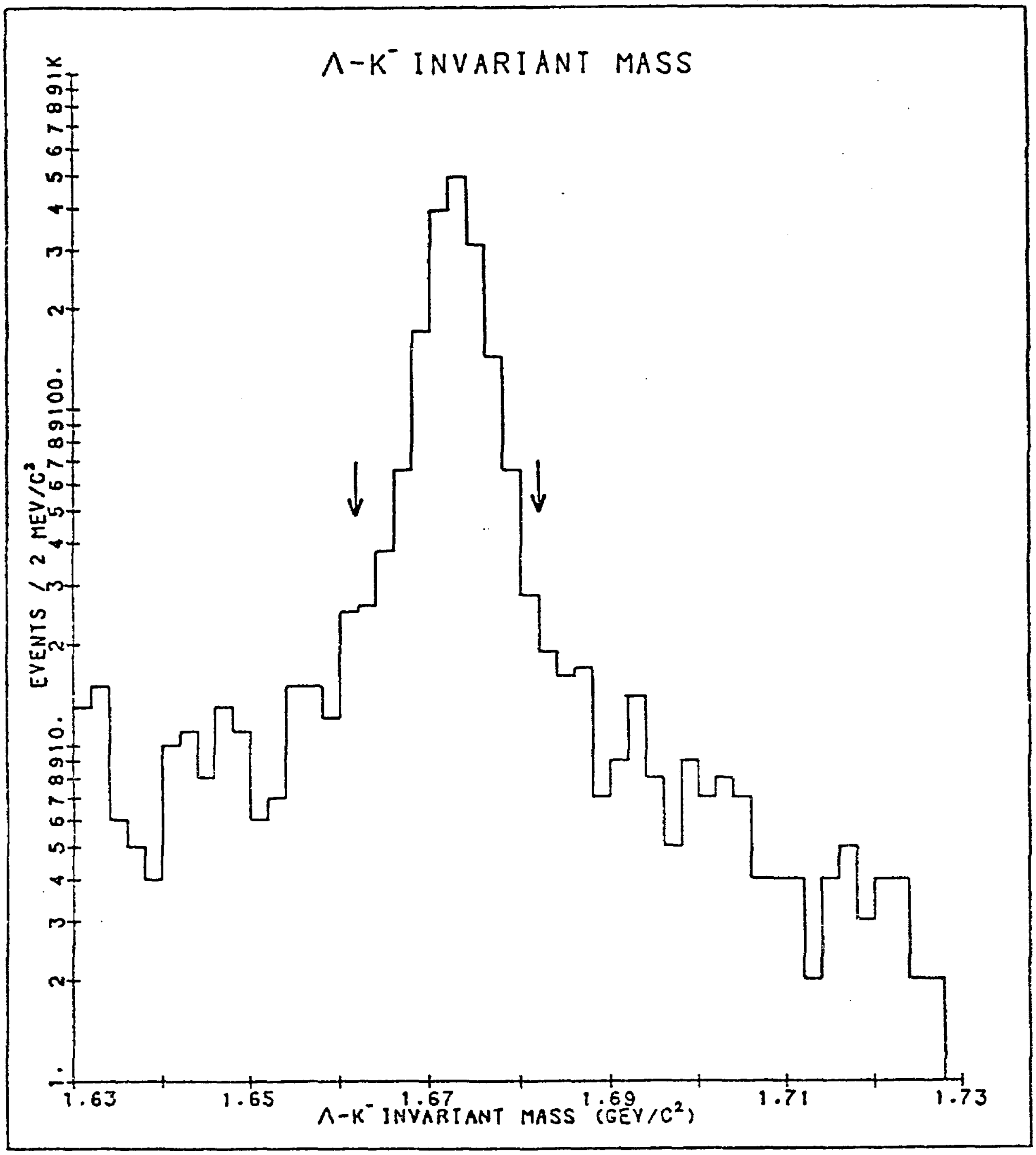


Figure 7b The distribution of the Λ-K^- invariant mass for events that satisfied all cuts but without the Λ-K^- invariant mass cut. Events outside the arrows were eliminated. Background events under the Ω^- peak are estimated to be about 10/bin. Note that this is a logarithm scale.

P800

A Precise Measurement of the Omega Minus Magnetic Moment

E 756

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A Progress Report

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Introduction

Baryon magnetic moment measurements play a fundamental role in improving our understanding of the behavior of quarks in hadrons. The simplest quark models correctly predict baryon magnetic moments to within 10% of the experimental data which are measured to better than 2% (Table 1). The disagreement with the data is significant and one must ask whether the differences can be understood in the framework of a standard quark model. More sophisticated quark models have introduced additional parameters to account for configuration mixing, relativistic corrections, and effective quark masses which are a function of their environment.[1] Even these models have difficulties in accommodating the precise hyperon measurements without losing their predictive power.

One expects the omega minus magnetic moment, μ_{Ω^-}, to be more amenable to calculation. It has as constituents three identical, spin parallel, relatively heavy quarks, thus making μ_{Ω^-} the most direct measurement of the strange quark magnetic moment. In the simplest quark models, μ_{Ω^-} is just three times the lambda magnetic moment, or -1.83 nuclear magnetons (n.m.). However, the corrections used in the more sophisticated models can destroy the equality between the lambda and the strange quark magnetic moments. With the effects needed to bring theory closer to the Σ and Ξ magnetic moment data, the best predictions for μ_{Ω^-} seem to be between -1.83 and -2.25 n.m.. Thus a measurement of μ_{Ω^-} at the ± 0.05 n.m. level is desirable to distinguish among contemporary theories. A 0.03 n.m. measurement, bringing the Ω^- precision into line with the other hyperons, should be sufficient for some time into the future.

The prerequisite to measuring a magnetic moment by spin precession is to have a polarized sample. The so-called "standard method" relies on the fact that hyperons produced by protons in inclusive reactions are polarized and that these hyperons live long enough to travel through a long, magnetic channel for spin precession.[2] This technique led to the precise set of hyperon magnetic moments measured by our group and others.[3] Prior to E756, no one had ever produced a polarized Ω^- beam. Thus we first proposed to try the "standard method". If the Ω^-'s were polarized, the experiment was designed to yield an error of less than 0.1 n.m. for the magnetic moment. We proposed to carry out a polarization analysis while data was being taken to determine the course of the experiment. If protons did not produce polarized Ω^-'s, we had devised alternative methods to produce the desired polarized sample.

During the 1987-88 fixed target run, the experiment proceeded as outlined in the proposal. Using a minimal statistically significant sample, we found the polarization of Ω^-'s produced directly by protons to be insufficient to accomplish the measurement. This result is in itself a major contribution to the understanding of the phenomena of inclusive hyperon polarization. In addition to the polarization results, this period of the experiment will yield the best measurement of the cascade minus magnetic moment (better than 1%), the best measurement of the weak decay parameter, α, for both the Ω^- and the Ξ^-, and the best measurement of the lifetime of both the Ω^- and the Ξ^-, good bread and butter physics.

With the enthusiastic assistance of the laboratory and its staff, we began implementing one of our alternate plans. From our previous experiments, we knew that a neutral beam produced at an angle was rich in polarized Λ's and Ξ^0's. Therefore we believed we could produce polarized Ω^- via spin transfer from a targeted polarized neutral hyperon beam. Because of the well designed optics of our proton beam, we had the flexibility of installing another targeting area and a neutral channel, just upstream of our charged hyperon channel. The laboratory very quickly built the simple neutral channel to our design and installed a target area capable of handling increased proton flux. While awaiting the installation of the new targeting scheme, which took about one month from request to delivery, we continued to take data, amassing the largest sample of Ω^-

events ever recorded (about 60,000) as well as significant numbers of antihyperons.

Our neutral beam was the first targeted polarized beam at the Tevatron and one of the few polarized high energy beams anywhere in the world. For the remainder of the fixed target run, about three calendar months, we collected about 20,000 Ω^-'s, enough to discover that the Ω^-'s were polarized and make the first statistically significant measurement of μ_{Ω^-} (± 0.2 n.m.). In addition, measurements of the Ω^- and Ξ^- spin transfer from the polarized neutral hyperon beam will provide new information for particle production models. The stage is now set to accomplish the primary goal of the E756 proposal, a precise measurement of μ_{Ω^-}.

The results of E756 to date underscore the ability of smaller scale experiments to probe for new phenomena and to succeed when a "standard method" no longer works. Experiments such as ours need few laboratory resources but these are crucial. We appreciate the 'can do' attitude of the laboratory management and the individual efforts and flexibility of the laboratory personnel. Without this help and encouragement, the first run of E756 could not have paid off so handsomely in physics and pointed the way toward our goal.

The "Standard" Method

Our experiments have always emphasized simplicity with just enough redundancy to assure a successful measurement. We have always been more interested in the physics than in the apparatus. In keeping with this spirit, our current spectrometer is based on a 2mm MWPC system which we have used many times before. To this, we have added a set of silicon strip detectors and 1mm wire chambers to track Ω^- just before and after it decays. The setup of E756 is shown in Figure 1. The major subsystems of the spectrometer, PWC's, SSD's, and counters, all work well. The trigger for the experiment is S1.S2.VBAR.M.C12R.C13L where counter coincidences S1.S2.VBAR define the hyperon beam and the multiplicity counter ($2 \leq M \leq 4$) and chamber hit pattern (right-half of C12 and left-half of C13) ensure the correct decay topology ($\Omega^- \rightarrow \Lambda K^-$ or $\Xi^- \rightarrow \Lambda\pi^-$, $\Lambda \rightarrow p\pi^-$). The reconstructed yield of events which fit our three track, two vertex topology is typically 20% of the triggers.

For direct production of Ω^-'s, the primary proton beam was incident at production angles ±2.5 mr on a Be target located directly upstream of the hyperon magnet (see Figure 2). Typically 6000 three-track triggers were recorded per spill of 2×10^{10} protons with a livetime of about 70%. The trigger rate was limited by the singles rates of 0.75 MHz in the MWPC's. After track reconstruction and cuts, we will have a total of 5 million Ξ^-'s and 60,000 Ω^-'s. The mass plots for Ω^- and Ξ^- are shown in Figure 3, exhibiting the cleanliness of our sample.

These events were then analyzed for polarization. The preliminary polarization analysis of a small sample of Ξ^- events is shown in Figure 4. The good agreement between this data and our 400 GeV (E620) data gives us confidence in our Ω^- results. Using a sample of 28,000 Ω^-'s, our preliminary analysis indicates that the magnitude of the Ω^- polarization is 0.027 ± 0.017 (see Figure 4), too small to accomplish a high precision measurement of μ_{Ω^-} in a limited amount of time.

The Spin Transfer Method

In our alternate scheme for producing polarized Ω^-'s, the primary proton beam was incident at production angles ±2 mr on a one interaction length copper target. The target was located directly upstream of a shielded B2 magnet which contained a simple two piece collimator with a 3 mm x 3 mm defining aperature (see Figure 5). The primary proton beam and charged secondaries were swept away by the field of the B2. The resulting polarized neutral beam was then incident at 0 mr on another one interaction length copper target directly upstream of the charged hyperon magnet.

The rate at which we accumulated data was limited by the proton intensity that was allowed in our simple target area. Our requested intensity was 7×10^{11} per spill which yielded an average intensity during running days of 2×10^{11} per spill. This average intensity is derived from our data taking history from mid-November, 1987 until the end of January, 1988 when both the accelerator and our experiment were in routine running mode (see Figure 6). Our quoted average intensity is simply the number of protons we used to produce Ω^-'s (1.55×10^{16}) divided by the number of days the accelerator was up (48). We believe the factor of three and a half reduction from peak (requested) to average intensity is an accurate way to estimate running time from requested intensity. This empirical reduction factor takes into account short accelerator down times, accelerator instabilities, dead spills, short experiment down times, and the time required for necessary calibration runs. To estimate calendar time, another factor must be included to account for accelerator or experiment down times which are on the order of a day or longer. During this three month period, the factor from runnning time to calendar time was 1.5.

At a primary proton intensity of 7×10^{11} per spill and with the charged hyperon magnet operating at a field integral of 14.5 T-m, the trigger rate was 300 per spill and the experiment was 95% live. The charged particle flux through the spectrometer, which is a limiting factor at 0.75 MHz, was approximately 0.15 MHz. The yield of good Ξ^- and Ω^- events per trigger was slightly higher (30%) for the spin transfer method than for the direct production. The Ξ^- to Ω^- ratio for both methods was 75. For a requested proton intensity of 7×10^{11} per minute, the average Ω^- yield was about 15 per hour. The total number of Ω^-'s collected during the 56 calendar days of data taking was 20,000.

The quality of the spin transfer data is represented by the cleanliness of the Ξ^- and Ω^- mass plots shown in Figure 7. These data were taken with the same trigger and have the same cuts applied as for those produced directly by protons. A comparison of Figures 3 and 7 shows no deterioration in quality using the neutral beam technique and our better understanding of the spectrometer as we proceeded. These data were analyzed for polarization as before, and both Ξ^-'s and Ω^-'s were found to be polarized (see Figure 8). At long last we have produced a beam of polarized Ω^-'s with a polarization, approximately 6%, sufficient to do a precision magnetic moment measurement. Data were also taken at higher magnetic fields of the charged hyperon channel to help plan a strategy for the next run. Higher magnetic fields correspond to higher average momenta (higher X_f). The Ξ^- polarization at the higher fields is also shown on Figure 8 and confirms a definite trend toward larger polarization (larger spin transfer) at higher momenta.

The 1989 Run Plan

The error in μ_{Ω^-}, $\delta(\mu_{\Omega^-})$, in units of n.m., is determined by the error in the polarization measurement and is given by

$$\delta(\mu_{\Omega^-}) = \left(\frac{2m_p S}{e}\right) \frac{\sqrt{3}}{\alpha_\Lambda P_\Lambda \int B dl \sqrt{N}}$$
$$= \frac{16.2}{\alpha_\Lambda P_\Lambda \int B dl \sqrt{N}}$$

where S is the spin of the Ω^-, m_p is the mass of the proton, e is the electric charge of the proton, $\int Bdl$ is the field integral of the charged hyperon magnet in units of T-m, $\alpha_\Lambda P_\Lambda$ is the measured asymmetry of the daughter lambda decay, and N is the number of Ω^-'s in the final sample. For the 1987-88 fixed target run, the $\int Bdl$ was 14.4 T-m, $\alpha_\Lambda P_\Lambda$ was 0.04±0.01, and N was 20,000, giving an error in μ_{Ω^-} of 0.2 n.m. (see Table 2, column 1). We propose to lower this error by about a factor of four during the first half of the next fixed target run in a straightforward manner as described below.

The largest factors we will employ in reducing the error in the magnetic moment measurement come from using an increased primary proton intensity, running for a longer time, and increasing the magnetic field in the charged hyperon magnet. We wish to increase the average primary proton intensity from a request of 7×10^{11} (2×10^{11} average) in the current run to 4.5×10^{12} (1.5×10^{12} average) in the 1989 run. This will be possible with an upgrading of the target area. At that intensity, the charged particle rate through our chambers will still be 0.4 MHz which is lower than our limit. By running for the first half of the next fixed target running cycle, we will also increase the data taking time from the 2 months (3 months calendar time) to 3 months (4.5 months calendar time).

We will also operate the hyperon magnet at its highest operating current which gives a field integral of 25.0 T-m. At the same time, the channel curvature will be changed to accept an average Ω^- momentum of 400 GeV. From the Ξ^- data, we expect the average Ω^- polarization to be about 10% at that momentum. The effect of the lower yield of Ω^- per incident proton on the magnetic moment precision at this higher momentum (see Figure 9) should be offset by the increased Ω^- polariation, giving no net loss. However, this lower yield is also true for pions in the negative beam. As a result, the charged particle flux through our chambers is also reduced, allowing us to run at the increased proton intensities required. To summarize, we want to collect 100,000 Ω^-'s taken at 25 T-m. This will be possible if we are given a total number of 2×10^{17} protons on target in the 1989 fixed target run.

These reasonably simple steps will result in improving the 0.2 n.m. error achieved in the 1987-1988 run to 0.03-0.06 n.m. for the next run, depending on the precise value of the Ω^- polarization. Other, smaller gains can probably be achieved by increasing the spatial acceptance of both the neutral and charged hyperon channels, using a beryllium target to produce the neutral beam with a higher average momentum, and additional background rejection by using spectrometer elements which were not needed in the exploratory phase of this experiment.

We emphasize that virtually no modifications to our existing spectrometer and beamline are necessary to make a measurement of this precision. Only the target area and the charged hyperon channel will be changed. With the long down time, including at least one summer before the next fixed target run, routine maintainance can easily be handled without disturbing the most important characteristic of our spectrometer which is that it is now ready for data taking. (See Figure 10 for our proposed startup schedule). Since no changes to online software or logic timing are planned, we can test the readiness of the spectrometer without beam. We feel confident that we can come up in a data taking mode in approximately 2 weeks after the beam first appears at our experiment.

Conclusion

We have shown both in this run and in the past that our group possesses both the understanding and the ability to make hyperon polarization measurements. By any definition, E756 was a success during the 87-88 fixed target run. Not only did we discover the effect which will allow us to fulfill our primary goal, but we will also extract much physics along the way. We request the opportunity to achieve the goal which is now within our grasp.

References

1. See for examples:
   - L. Brekke and J. Rosner, University of Chicago preprint EFI 87-80 (1987),
   - A. Mahohar and H. Georgi, Phys. Lett. 132B, 183(1983),
   - H. J. Lipkin, Nucl. Phys. B241, 477(1984), and Nucl. Phys. B214, 136(1983),
   - G. Brown and S. Myrher, Phys. Lett. 128B, 229(1983),
   - J. Franklin, Phys. Rev. D30, 1542(1984).

2. G. Bunce et al, Phys. Rev. Lett. 36, 1113(1976)

3. L. Schachinger et al, Phys. Rev. Lett. 41, 1348(1978),
   P. T. Cox et al, Phys. Rev. Lett. 46, 877(1981),
   C. Ankenbrandt et al, Phys. Rev. Lett. 51, 863(1983),
   R. Rameika et al, Phys. Rev. Lett. 52, 581(1984),
   G. Zapalac et al, Phys. Rev. Lett. 57, 1526(1986),
   C. Wilkinson et al, Phys. Rev. Lett. 58, 855(1987).

	experiment	exact SU(6)	broken SU(6)
p	2.794	input	input
n	-1.913	-1.86	input
Λ	-0.613±0.005	-0.93	input
Σ^+	2.38±0.02 2.479±0.025	2.79	2.67
Σ^0		0.93	0.79
Σ^-	-1.166±0.017	-0.93	-1.09
$\Sigma\rightarrow\Lambda$	-1.59±0.09	-1.63	1.42
Ξ^0	-1.250±0.014	-1.86	-1.44
Ξ^-	-0.69±0.04	-0.93	-0.49
Ω^-		-2.79	-1.84

Baryon Magnetic Moments

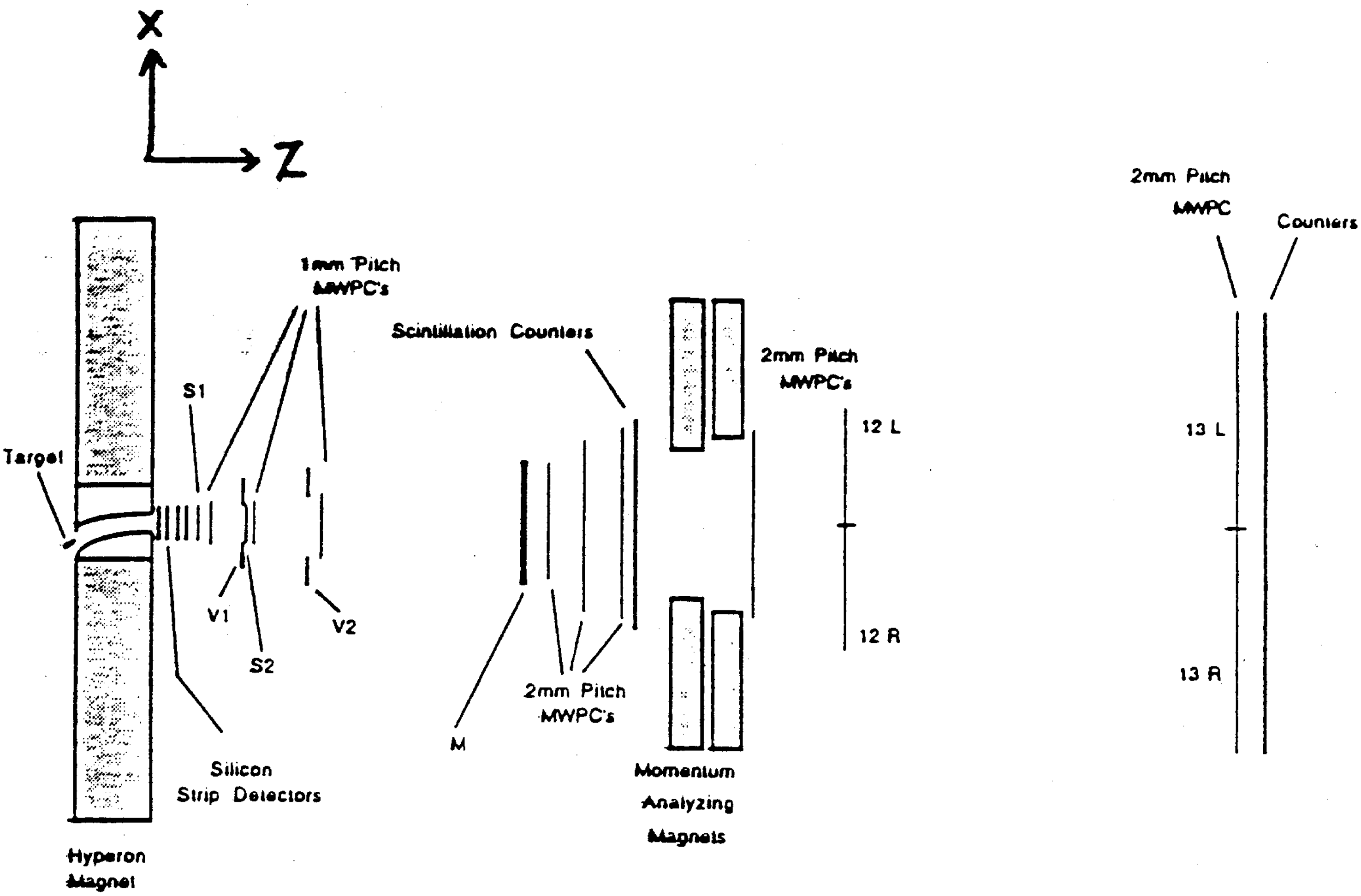
TABLE 1 Current experimental determinations of the hyperon magnetic moments along with predictions for the simplest quark models.

$$\delta\mu_{\Omega^-} = \frac{16.2}{(\alpha P)\int Bdl\sqrt{N}}$$

	'87-'88	proposed
$\int Bdl$	14.5	25.0
(αP)	0.04	0.06
N	20000	100000
ΔT	2 months	4 months
<I>	4 x10^{11}	2 x10^{12}
$\delta\mu_{\Omega^-}$	**0.2 n.m.**	**0.03 n.m.**

Error in Magnetic Moment Measurement

TABLE 2 - We show the factors which go into determining the error in the magnetic moment. In order to obtain 100000 events we need a total integrated intensity of 2E17 protons on target. The Delta T and average I shown are way to achieve this, however one must be careful when interpreting the T and I.

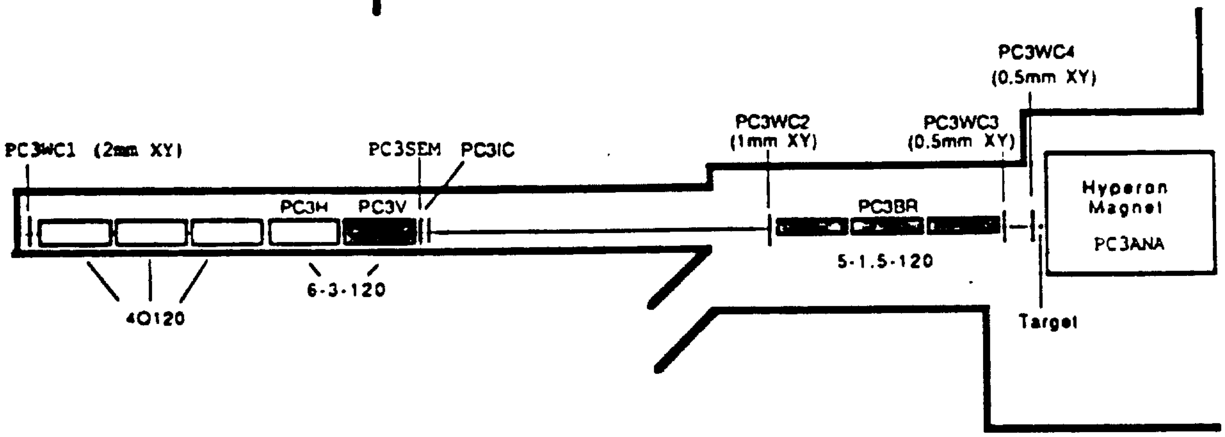


Plan View of E756 Spectrometer (not to scale)

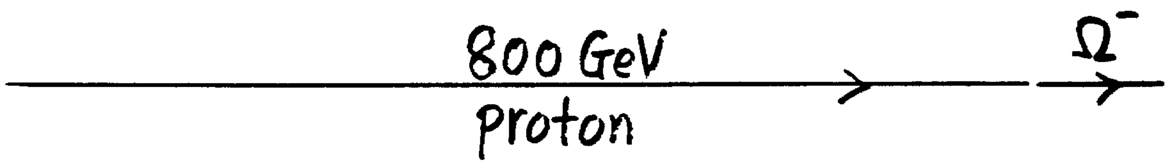
FIGURE 1

Part I

$$p + Be \rightarrow \Omega^- + x$$



Plan view



Elevation view

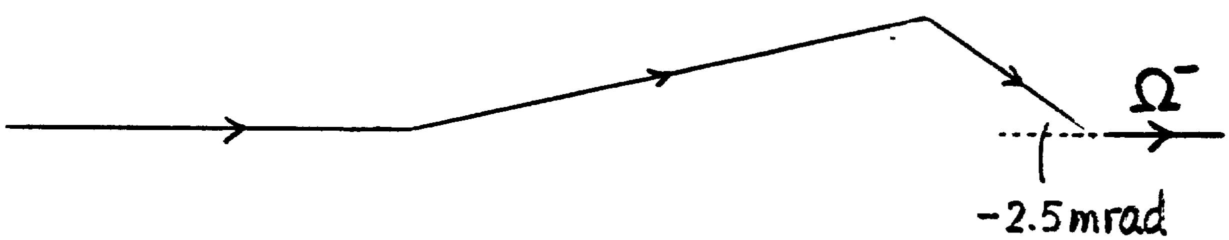


FIGURE 2 - Layout of PC3 pre-target area for E756 when producing Omegas directly from protons.

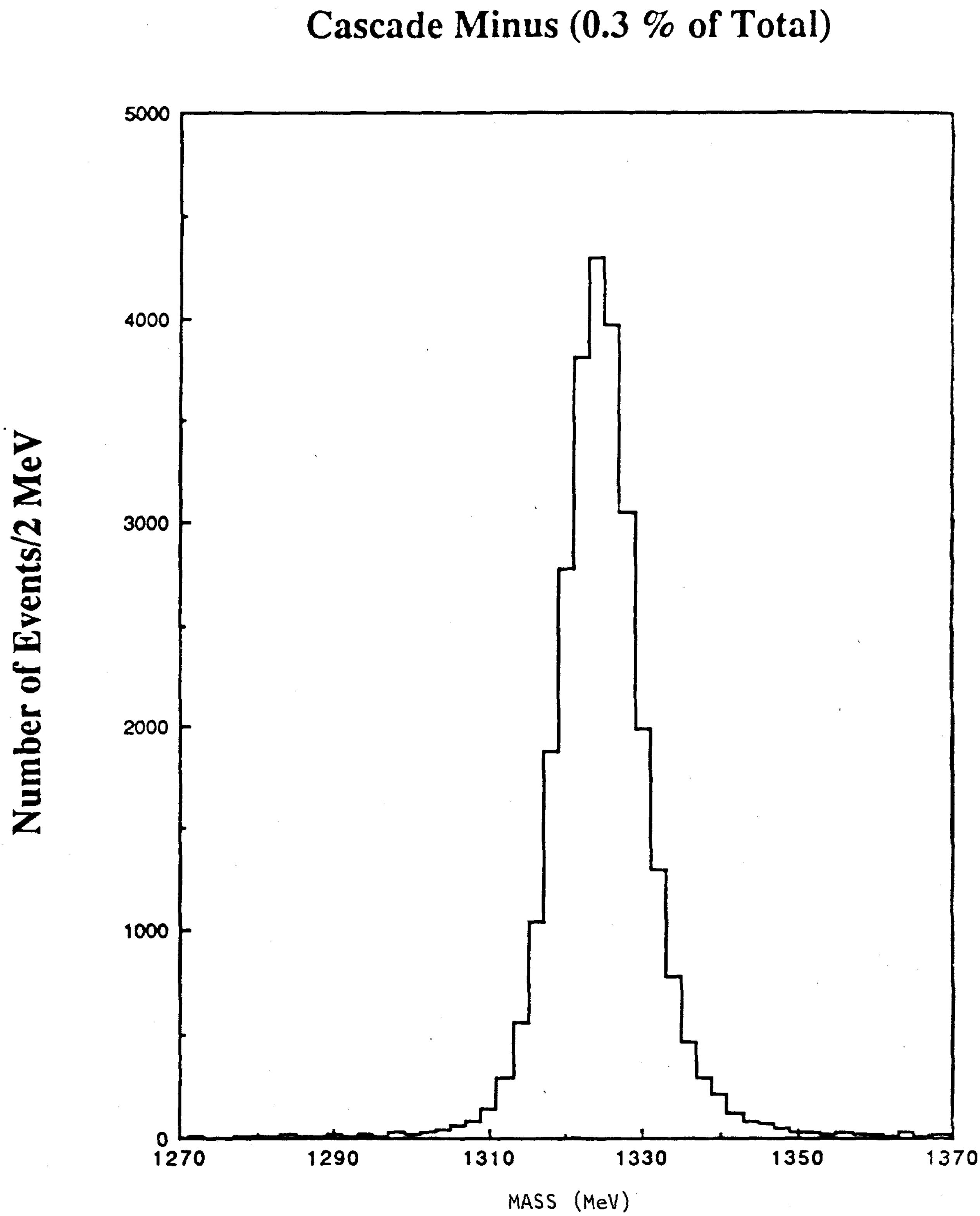


Figure 3a - Mass plot for a small sample of Cascades produced by protons

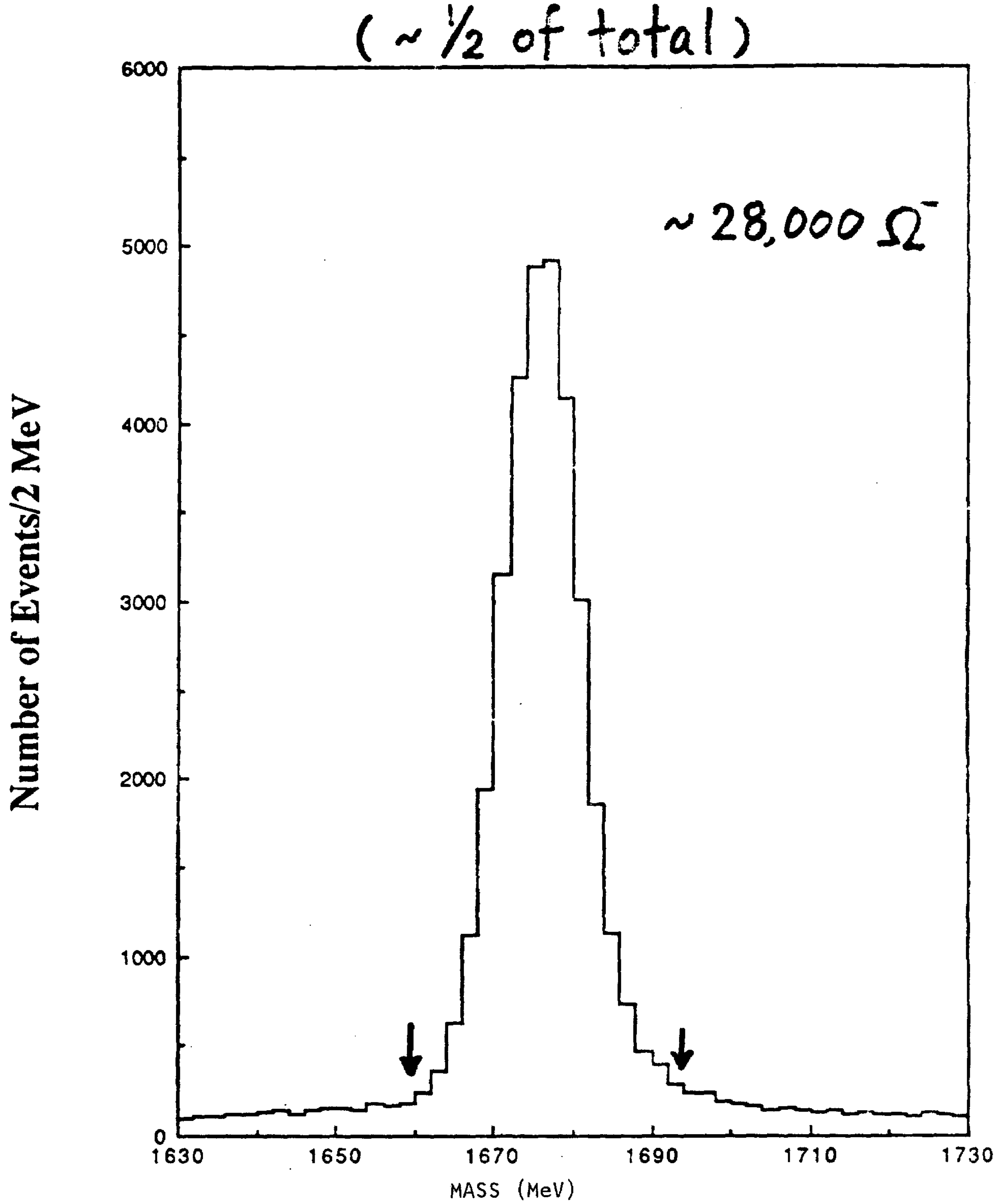


Figure 3b - Mass plot for 28000 Omegas produced by protons. The arrows indicate where the data was cut for the polarization analysis.

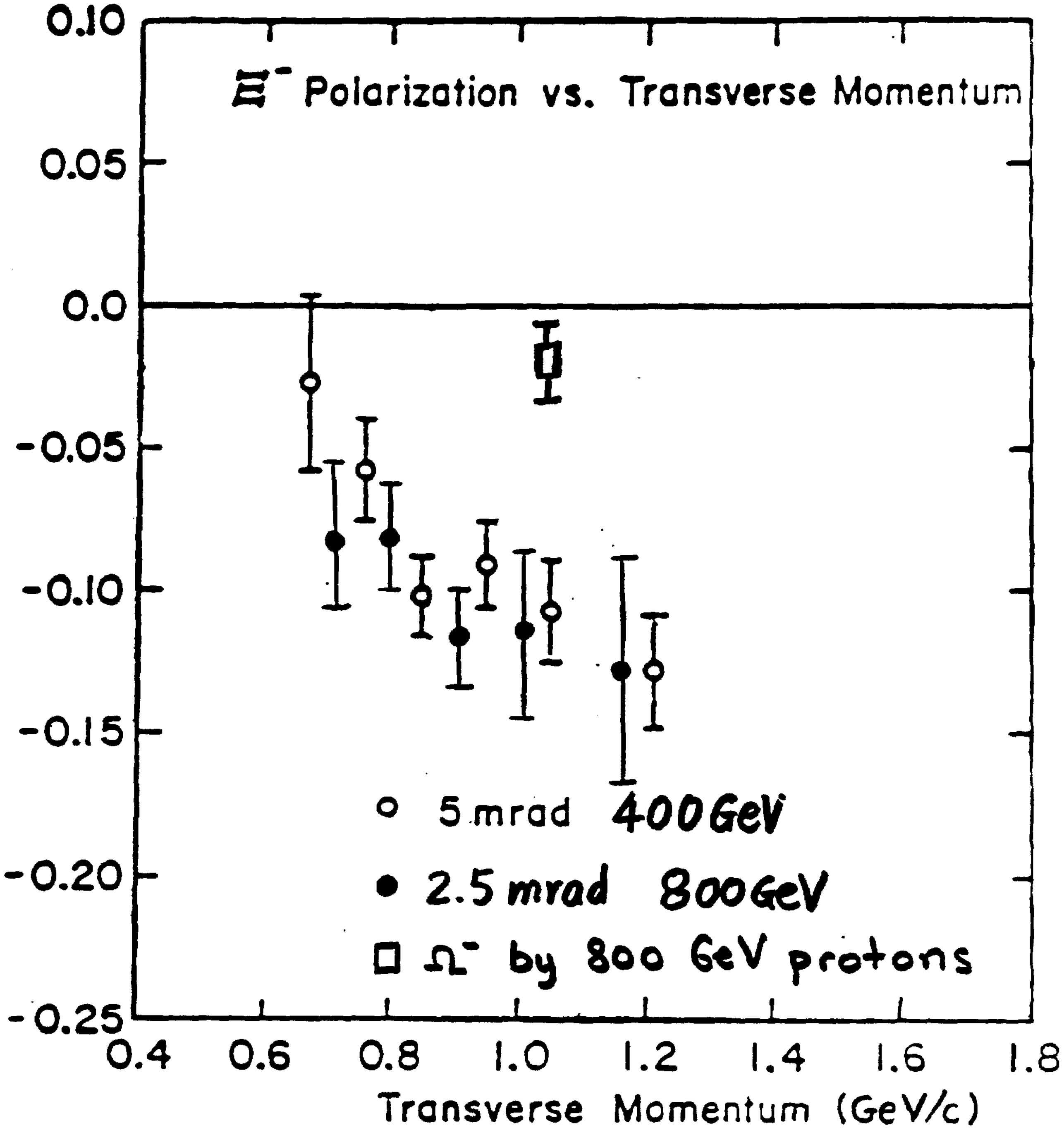
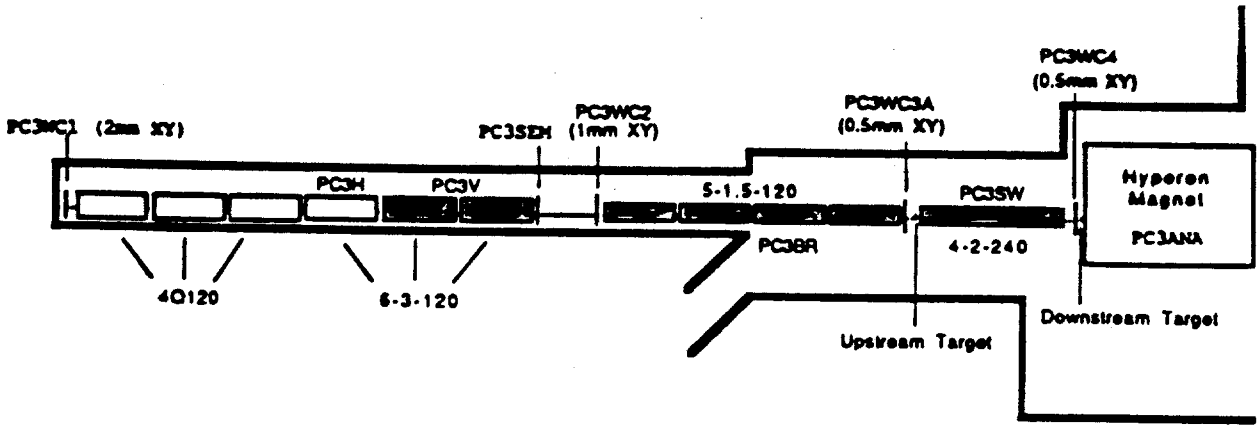


FIGURE 4 - Preliminary polarization results for a small sample of Cascades from E756 is shown with cascade polarization measured in E620 (400 GeV). The polarization result for 28000 Omegas (produced by protons) is also shown.

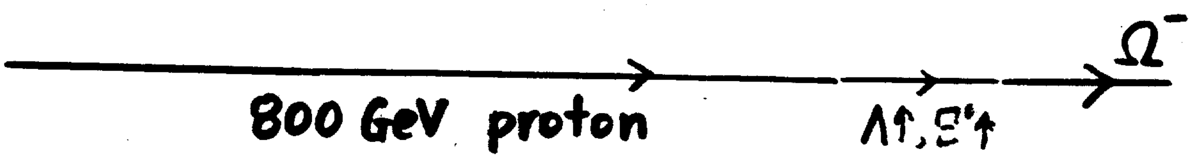
Part II

$$p + Cu \rightarrow \Lambda\uparrow, \Xi^0\uparrow$$

$$\Lambda\uparrow, \Xi^0\uparrow + Cu \rightarrow \Omega^- + X$$



Plan View



Elevation View

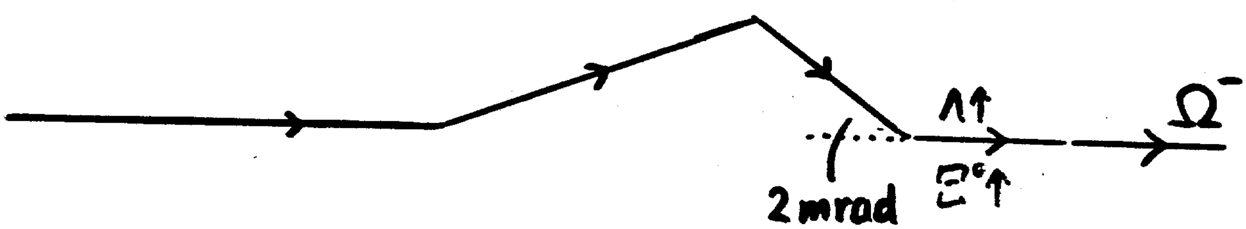


FIGURE 5a - The PC3 pre-target area is shown for the neutral beam targeting scheme.

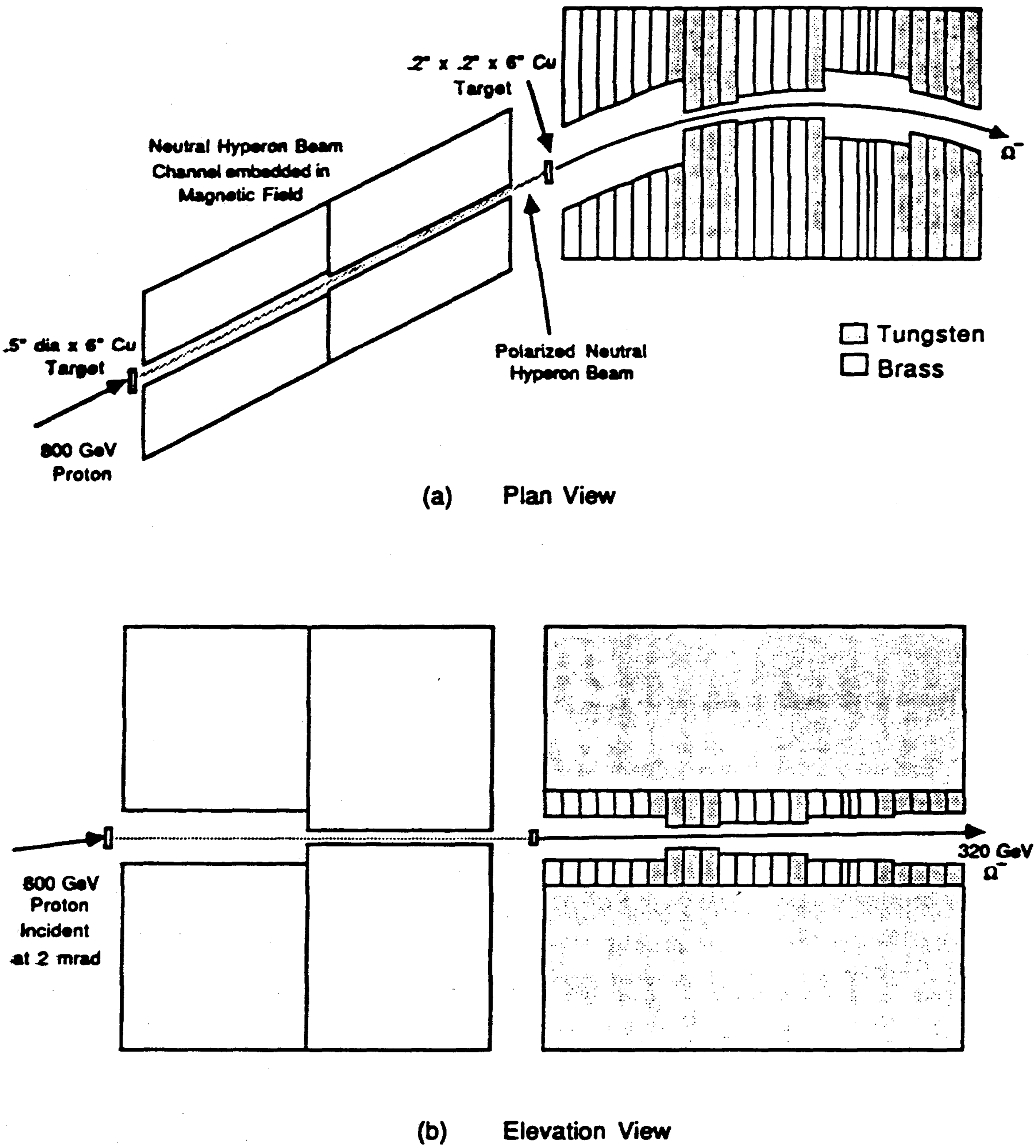


FIGURE 5b - Detail of the neutral beam channel imbedded in the B2 magnet, and the charged beam channel imbedded in the momentum selecting, spin precession magnet.

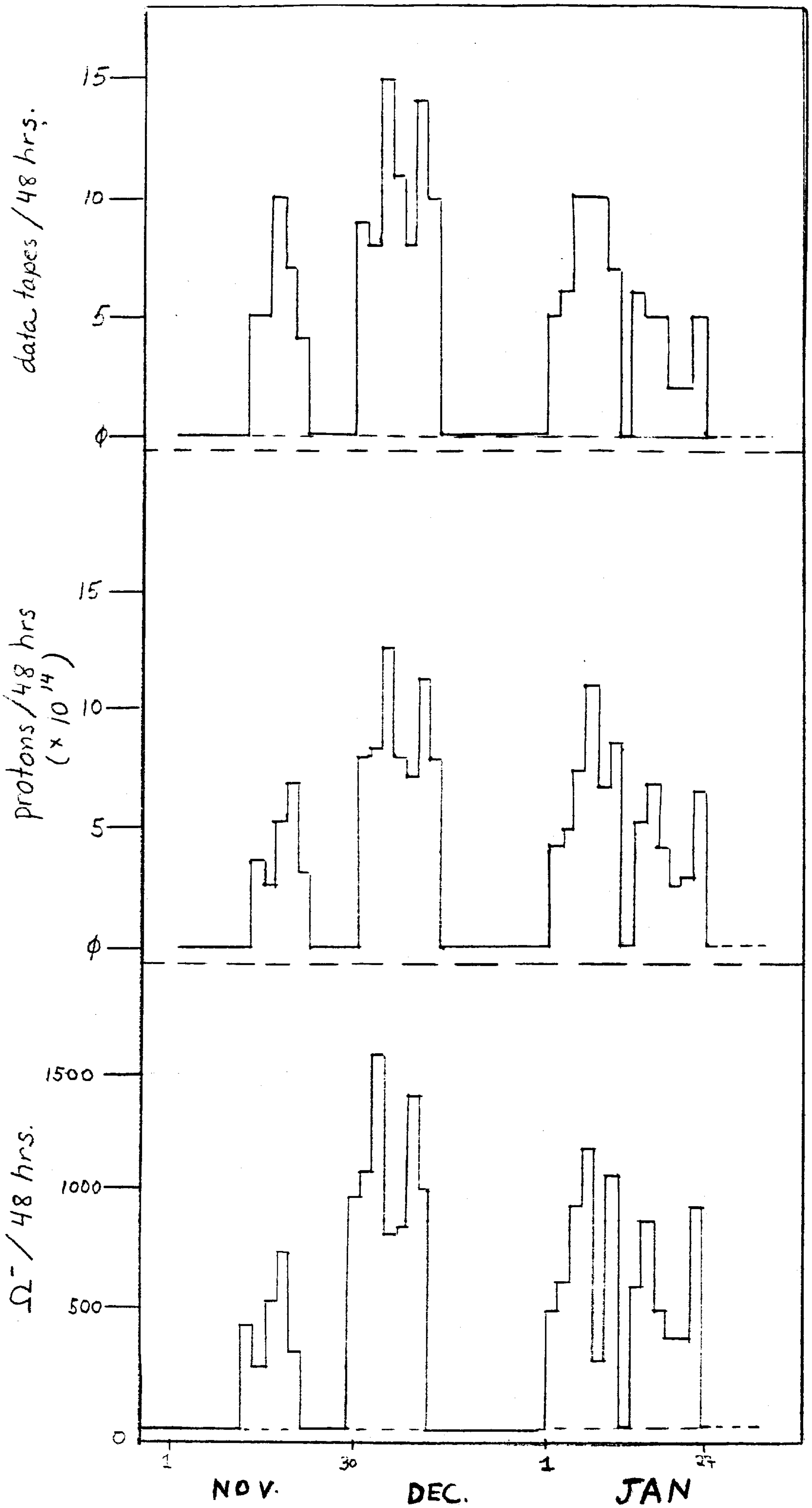


Figure 6 - E756 data taking history from Nov. 13, 1987 until January 27, 1988. This is the period during which all of the polarized Omega data was taken.

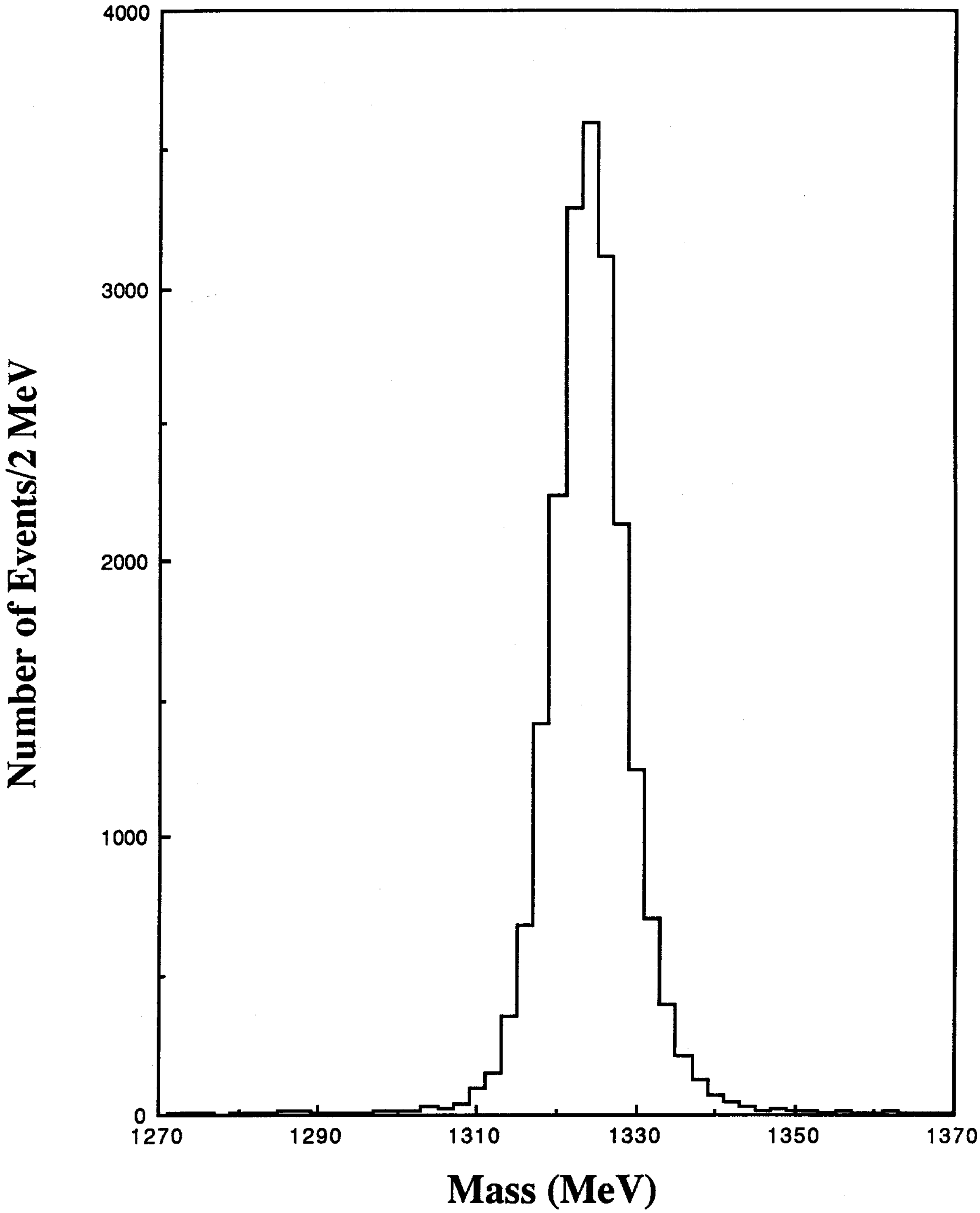


Figure 7a - Mass plot for a sample of Cascades produced by the neutral beam.

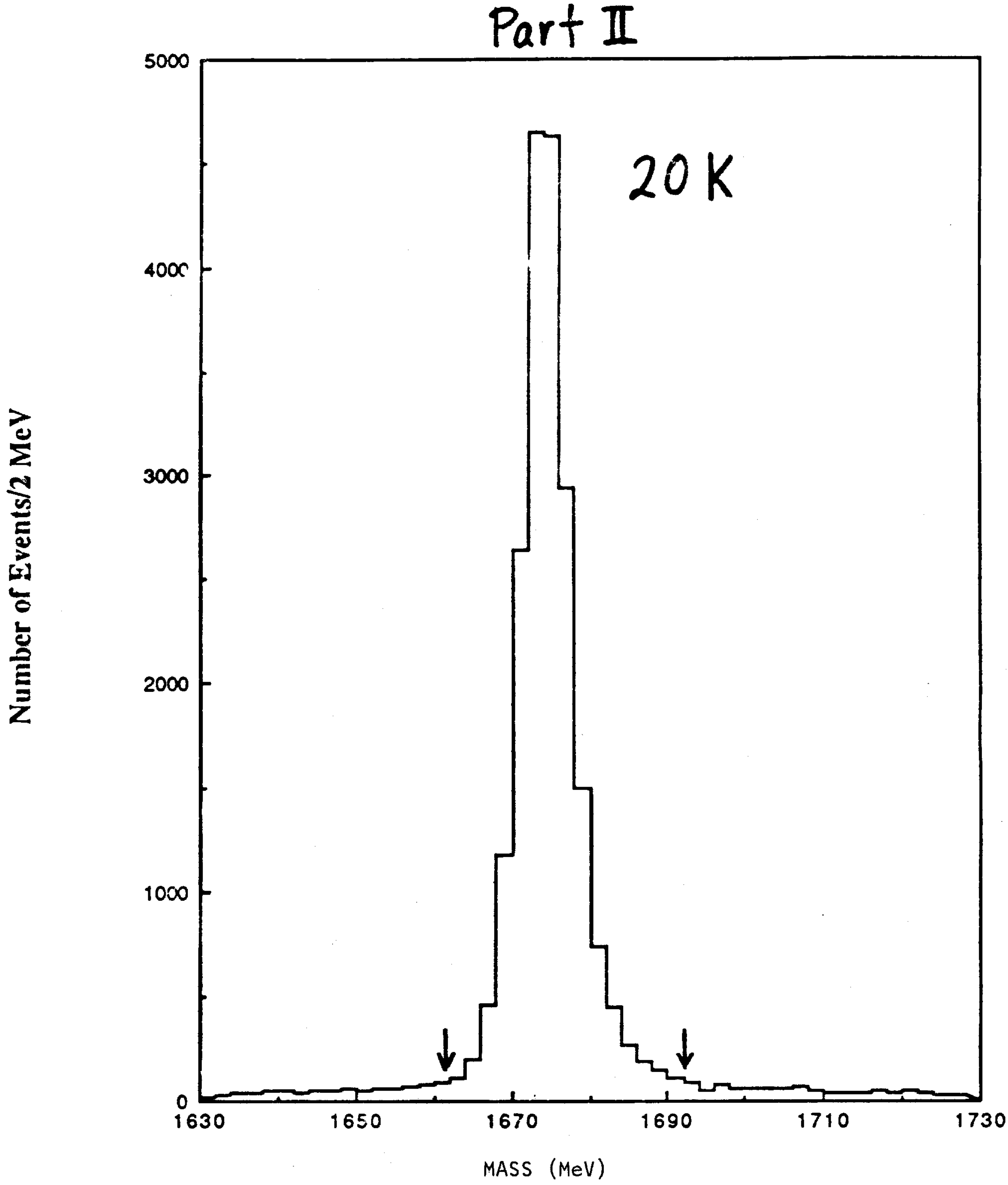


FIGURE 7b - Mass plot for Omegas produced by a neutral beam. Again the arrows indicate where the data were cut for use in the polarization analysis.

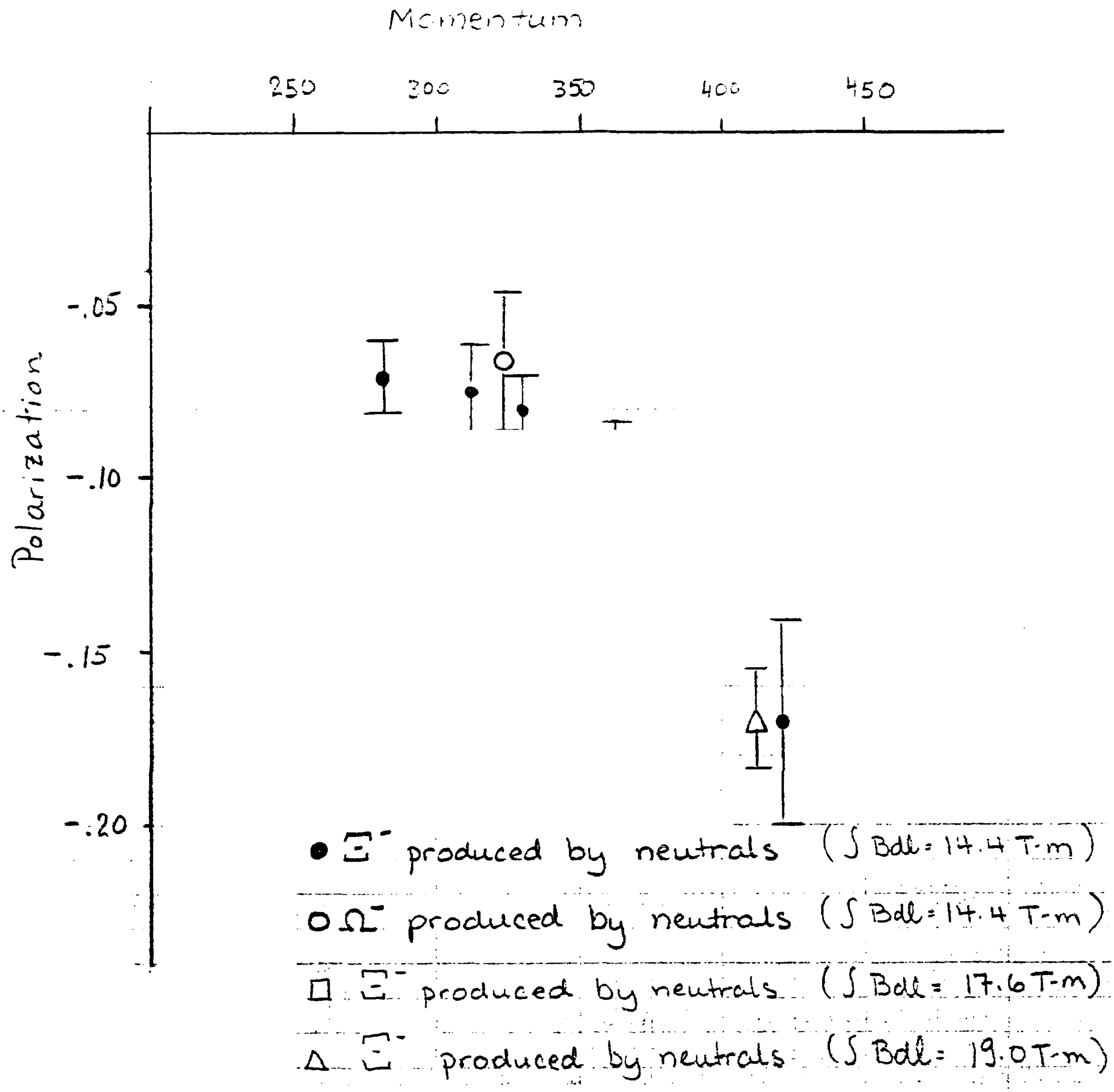


FIGURE 8 - PRELIMINARY results of polarization for neutral beam production of Cascades and Omegas.

E756

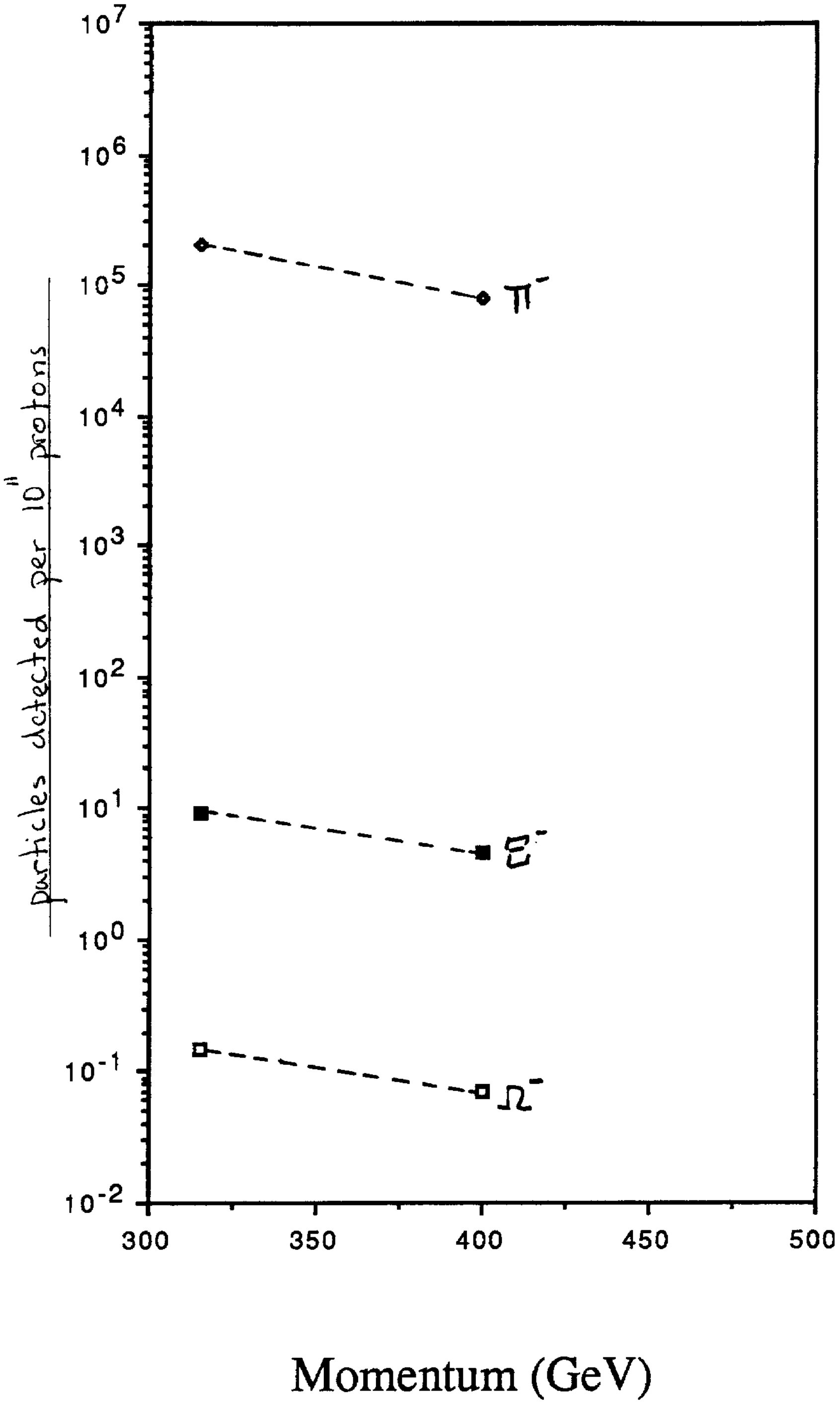


FIGURE 9 - Particle flux for pi's, cascades and omegas for neutral beam production. Note, the rates are per 1E11 protons on target.

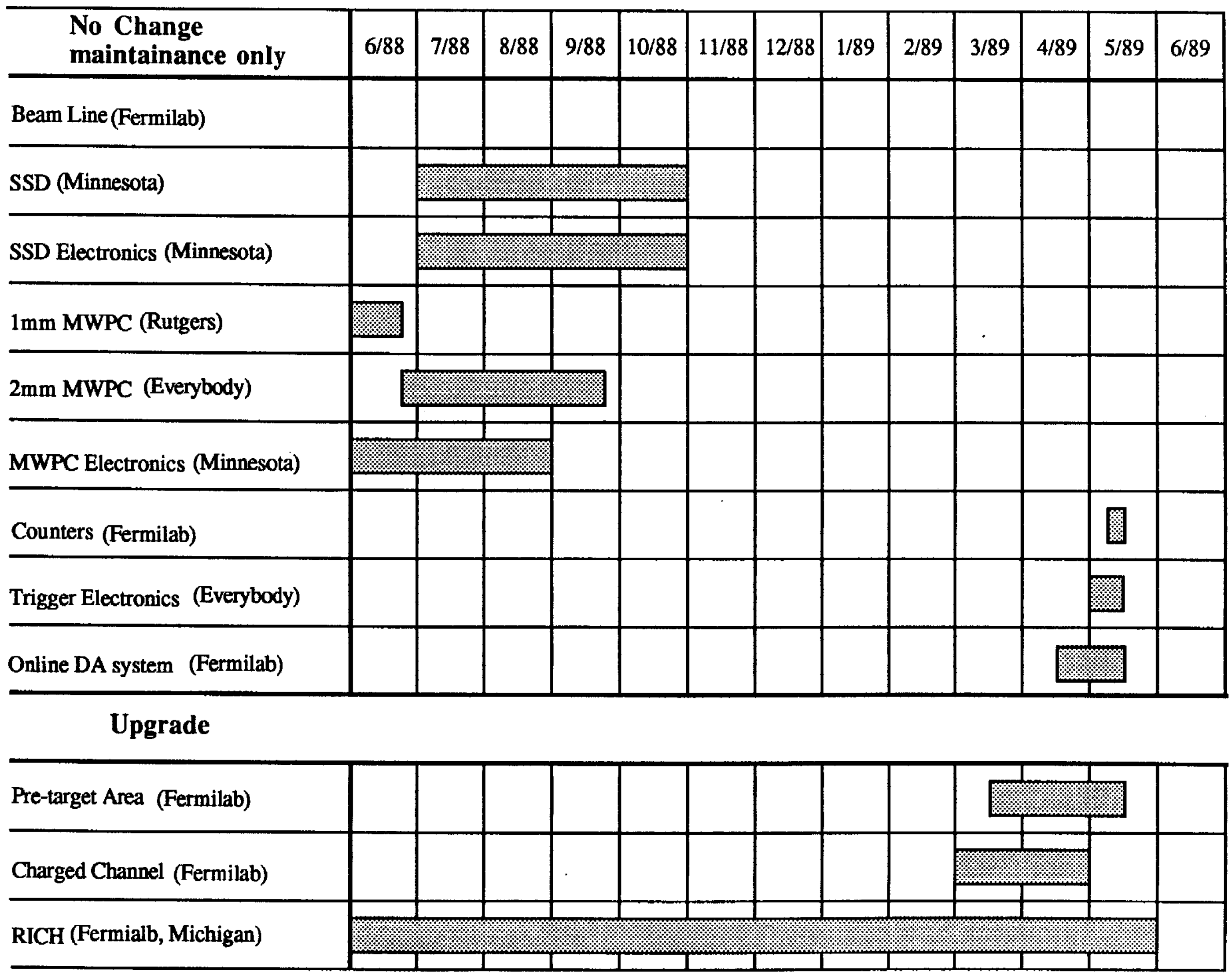


FIGURE 10 - **1989 Start-up Schedule of E756**